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(Volume 2)

FINAL REPORT ON

A STUDY OF SPACECRAFT TECHNOLOGY AND DESIGN CONCEPTS

Volume 2, Appendices

A. Operations

B. Spacecraft 90 Survivability

C. Evaluation/Selection Criteria

NASA/LaRC Contract with

Rockwell International

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Satellite Systems Division

Rockwell International

FOREWORD

The Satellite Systems Division of Rockwell International has been conducting a Study of Spacecraft Technology and Design Concepts. This work was performed under Contract NAS1-17785 for the Langley Research Center, National Aeronautics and Space Administration. NASA Leadership was provided through the office of Aeronautics and Space Technology, Dr. Leonard A. Harris, Director for Space, and through the Langley Research Center, Space Systems Division, Lloyd S. Keefer, Jr., Representative of the Contracting Officer.

This report documents the findings of that study, discussing concepts for advancing the state of the art in the design of unmanned spacecraft, the requirements that gave rise to its configuration, and the programs of technology that are suggested as leading to its eventual development. Volume I contains the major technical documentation of the study. Volume II consists of 3 Appendices (Operations, Survivability, and Evaluation Criteria) that might be of particular interest to some readers.

The work was conducted under the direction of F. A. Zylius, Rockwell's Study Manager and Supervisor of Systems & Operations Analysis. The following made major contributions to this study:

C. E. Hiers, Structures & Materials

R. J. Pietka, Spacecraft Design

B. Berman, Electrical Power

T. W. Tysor, Thermal Control

E. J. Filardo, Data Management

G. C. McGee, Guidance, Navigation, Control

P. Ramirez, Propulsion

D. S. Mercadante, Communications

J. W. Haffner, Radiation Survivability

P. R. Fagan, Operations Analysis

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APPENDIX A. OPERATIONS

SUMMARY OF IMPACTS ON SUBSYSTEMS AIDED IN THE DEFINITION OF CONFIGURATION CONCEPTS

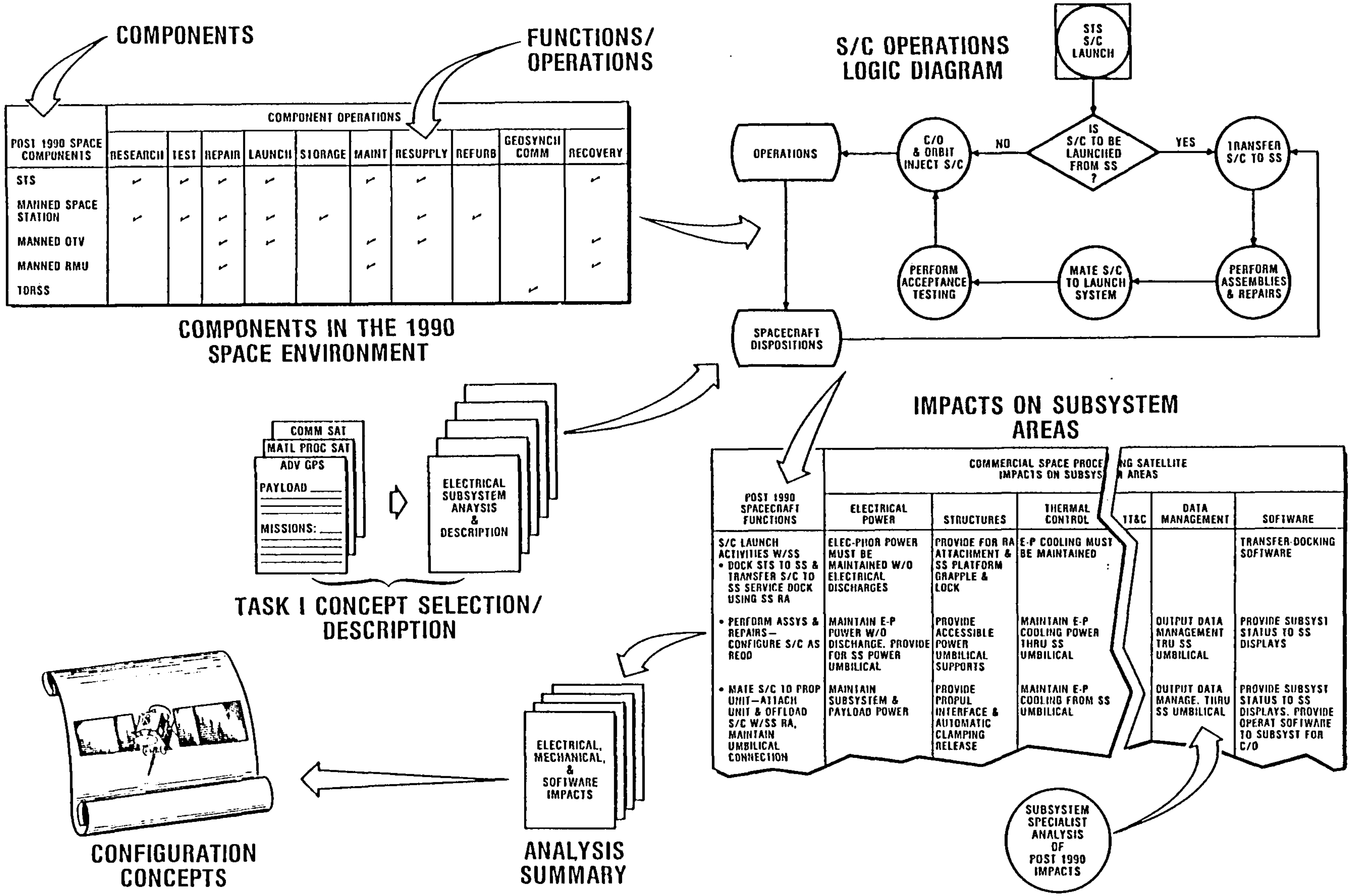
The figure illustrates operations studies performed during the contract and included in this Appendix.

Space components of the post-1990 space environment were identified and their potential interfaces with S/C-90 needs were defined. Specialists defined resulting impacts on the SC-90 configurations and subsystems.

An analysis summary of the major subsystem impacts was performed and the results formatted and tabulated in the disciplinary areas: electrical/electronic, mechanical, and software.

The subsystem impacts served as a guide to the subsystem engineer and configuration concept designer.

SUMMARY OF IMPACTS ON SUBSYSTEMS AIDED IN THE DEFINITION OF CONFIGURATION CONCEPTS



POST 1990 SPACE COMPONENTS	COMPONENT OPERATIONS									
	RESEARCH	TEST	REPAIR	LAUNCH	STORAGE	MAINT	RESUPPLY	REFURB	GEOSYNCH COMM	RECOVERY
STS	✓	✓	✓	✓		✓	✓			✓
MANNED SPACE STATION	✓	✓	✓	✓	✓		✓	✓		
MANNED OTV			✓	✓		✓	✓			✓
MANNED RMU			✓			✓				✓
TDRSS									✓	

POST 1990 SPACECRAFT FUNCTIONS	COMMERCIAL SPACE PROCE NG SATELLITE IMPACTS ON SUBSYS N AREAS					
	ELECTRICAL POWER	STRUCTURES	THERMAL CONTROL	TT&C	DATA MANAGEMENT	SOFTWARE
S/C LAUNCH ACTIVITIES W/SS • DOCK STS TO SS & TRANSFER S/C TO SS SERVICE DOCK USING SS RA	ELEC-PROP POWER MUST BE MAINTAINED W/O ELECTRICAL DISCHARGES	PROVIDE FOR RA ATTACHMENT & SS PLATFORM GRAPPLE & LOCK	E-P COOLING MUST BE MAINTAINED			TRANSFER-DOCKING SOFTWARE
• PERFORM ASSYS & REPAIRS— CONFIGURE S/C AS REQD	MAINTAIN E-P POWER W/O DISCHARGE. PROVIDE FOR SS POWER UMBILICAL	PROVIDE ACCESSIBLE POWER UMBILICAL SUPPORTS	MAINTAIN E-P COOLING POWER THRU SS UMBILICAL		OUTPUT DATA MANAGEMENT TRU SS UMBILICAL	PROVIDE SUBSYST STATUS TO SS DISPLAYS
• MATE S/C TO PROP UNIT—ATTACH UNIT & OFFLOAD S/C W/SS RA, MAINTAIN UMBILICAL CONNECTION	MAINTAIN SUBSYSTEM & PAYLOAD POWER	PROVIDE PROPUL INTERFACE & AUTOMATIC CLAMPING RELEASE	MAINTAIN E-P COOLING FROM SS UMBILICAL		OUTPUT DATA MANAGE. THRU SS UMBILICAL	PROVIDE SUBSYST STATUS TO SS DISPLAYS. PROVIDE OPERAT SOFTWARE TO SUBSYST FOR C/O

IDENTIFICATION OF SPACE COMPONENTS & OPERATIONS DEFINES THE POST 1990 SPACE ENVIRONMENT

The Task I model and scenario development which was performed early in the contract was employed to establish the post 1990 space components, and their activities and operations relative to S/C-90 needs.

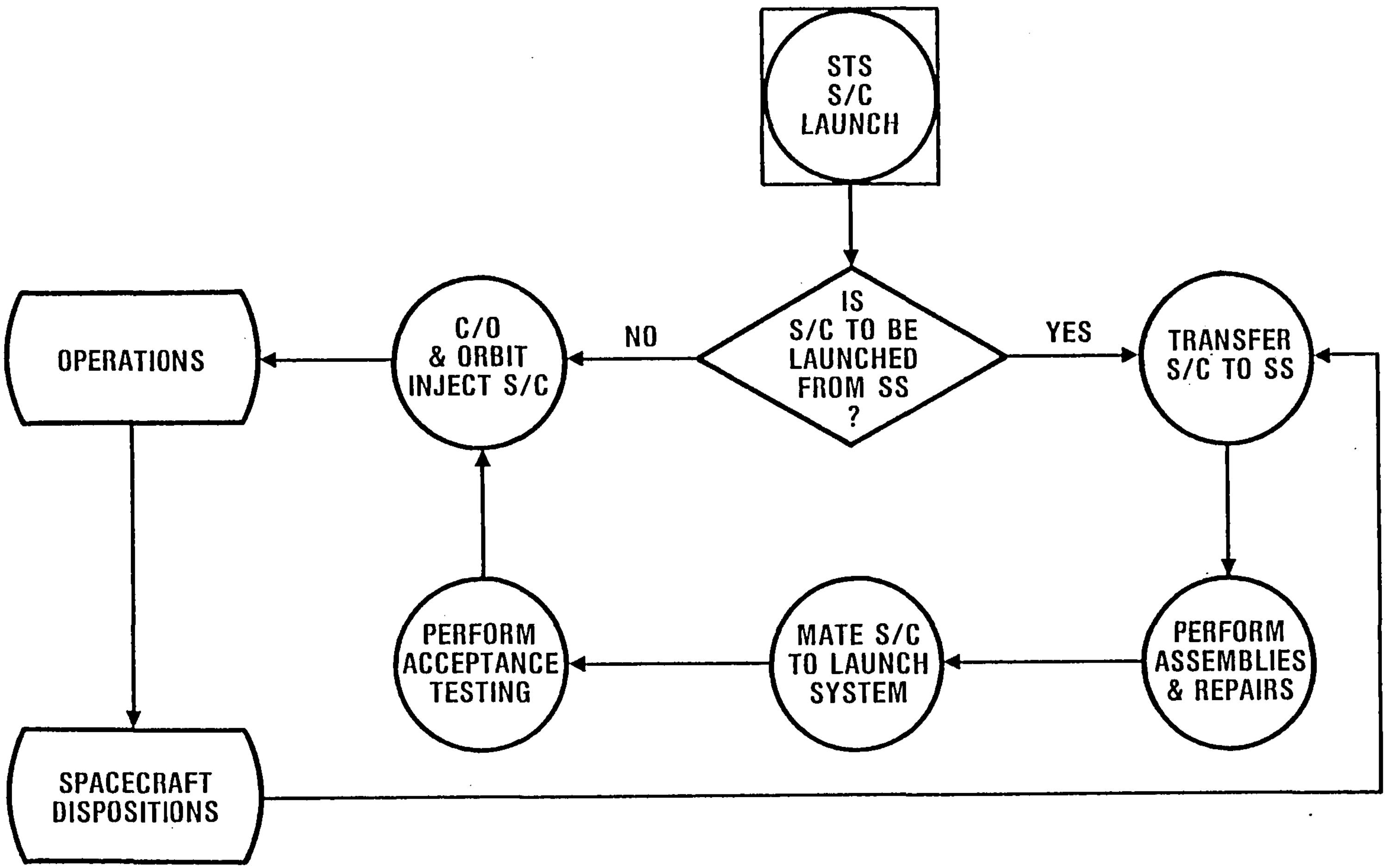
IDENTIFICATION OF SPACE COMPONENTS & OPERATIONS DEFINES THE POST 1990 SPACE ENVIRONMENT

POST 1990 SPACE COMPONENTS	COMPONENT OPERATIONS									
	RESEARCH	TEST	REPAIR	LAUNCH	STORAGE	MAINT	RESUPPLY	REFURB	GEOSYNCH COMM	RECOVERY
STS	✓	✓	✓	✓		✓	✓			✓
MANNED SPACE STATION	✓	✓	✓	✓	✓		✓	✓		
MANNED OTV			✓	✓		✓	✓			✓
MANNED RMU			✓			✓				✓
TDRSS									✓	

LOGIC DIAGRAM IDENTIFIES S/C LAUNCH OPERATIONS IN THE POST 1990 SPACE ENVIRONMENT

Logic diagrams were developed which defined S/C-90 activities within the post 1990 space environment. The illustration is of S/C-90 launch interfaces with both STS & Space Station (SS). It has been assumed that SS interface operations will include repair, assembly, checkout, and testing. Logic diagrams of post 1990 S/C-90 interface activities in the areas of mission operations and dispositions can be found on the following pages.

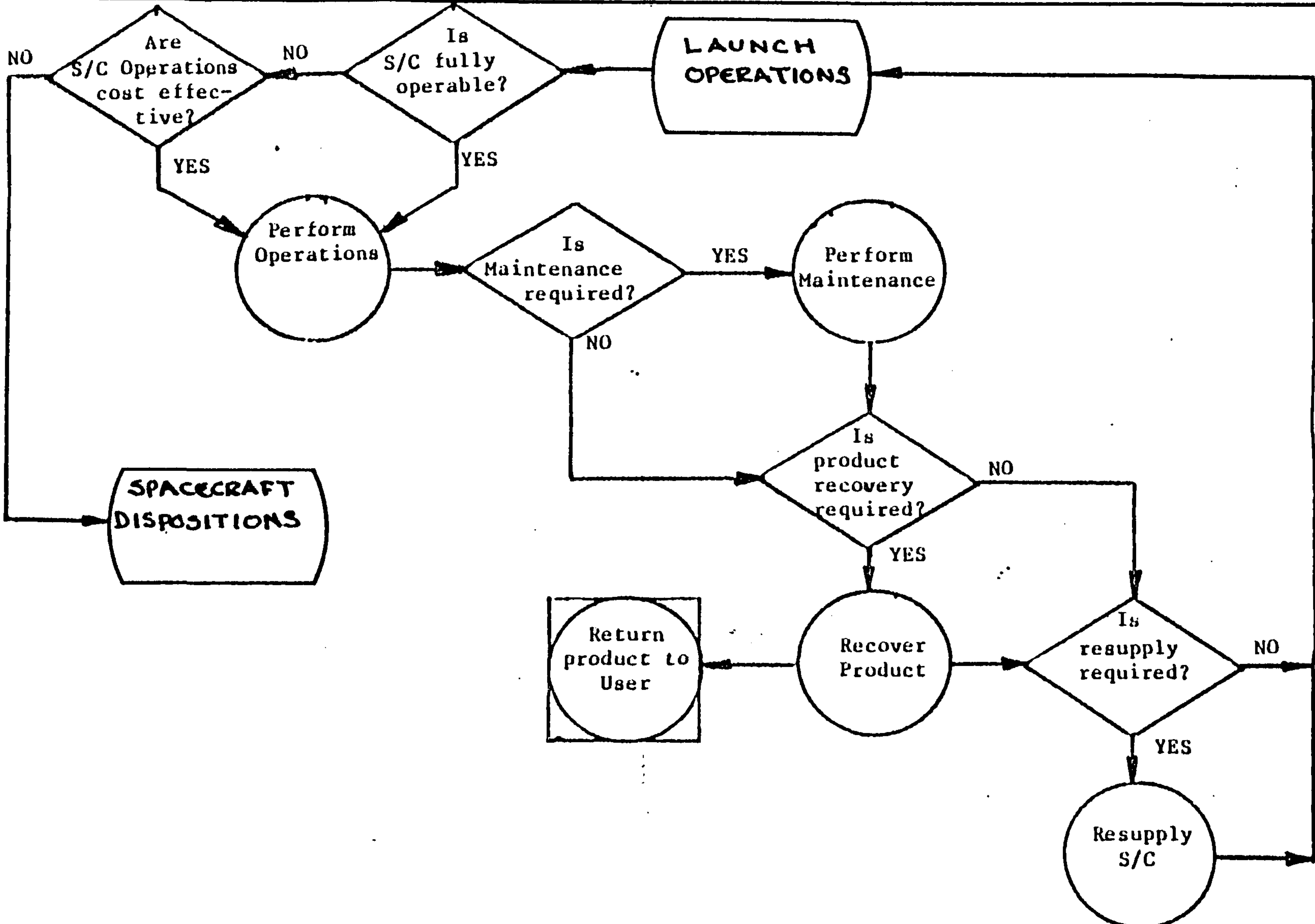
LOGIC DIAGRAM IDENTIFIES S/C LAUNCH OPERATIONS IN THE POST 1990 SPACE ENVIRONMENT



LOGIC DIAGRAM IDENTIFIES S/C OPERATIONS IN THE POST 1990 SPACE ENVIRONMENT

The logic diagram for the potential S/C-90 mission operations and activities is illustrated. In the post 1990 space environment it is anticipated that on-orbit servicing will be commonplace.

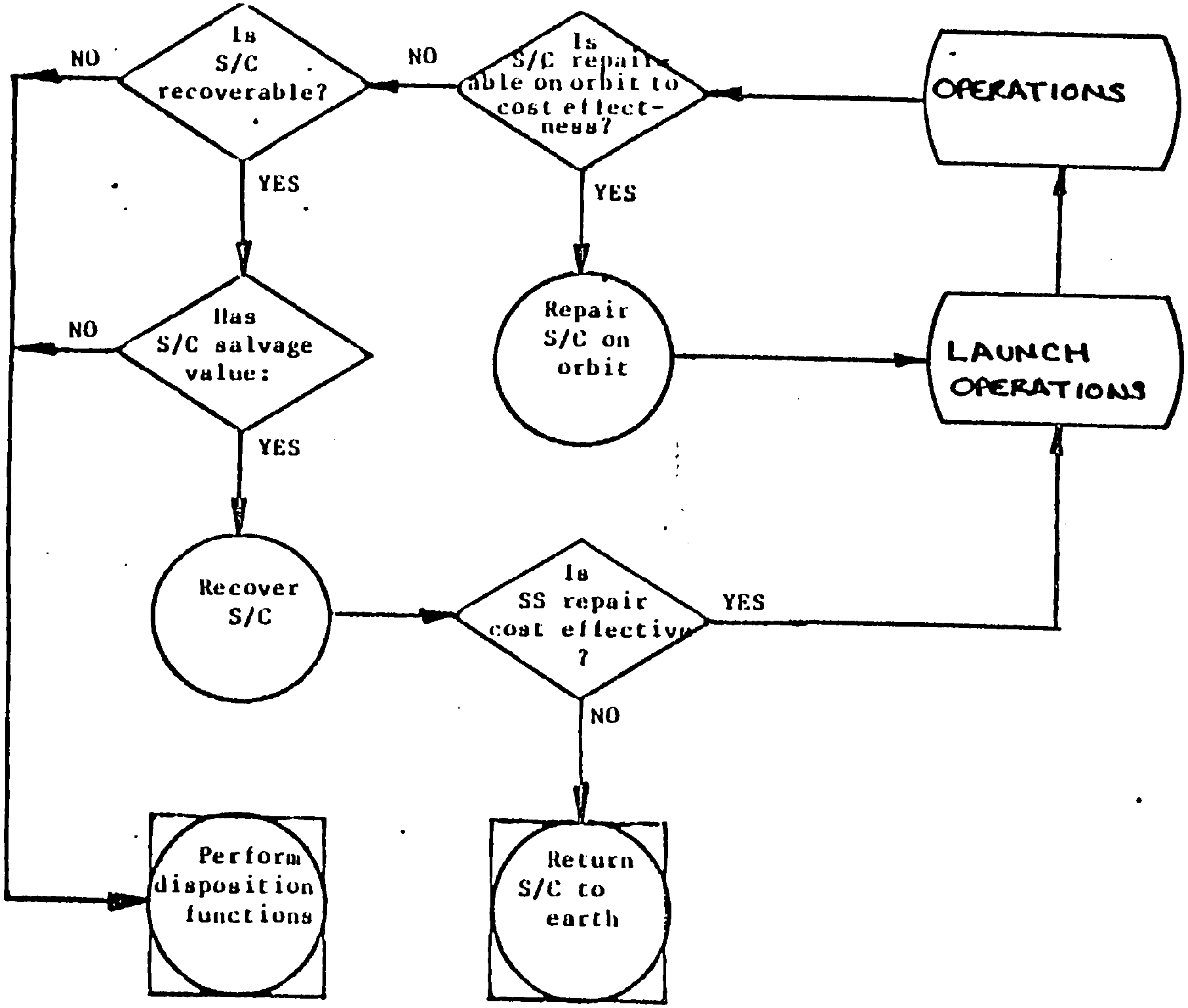
LOGIC DIAGRAM IDENTIFIES S/C MISSION OPERATIONS IN THE POST 1990 SPACE ENVIRONMENT



LOGIC DIAGRAM IDENTIFIES S/C DISPOSITIONS IN THE POST 1900 SPACE ENVIRONMENT

Potential S/C-90 disposition operations are illustrated. Disposition operations include: recovery for repair at Space Station, return to earth for salvage or upgrade, and destruction.

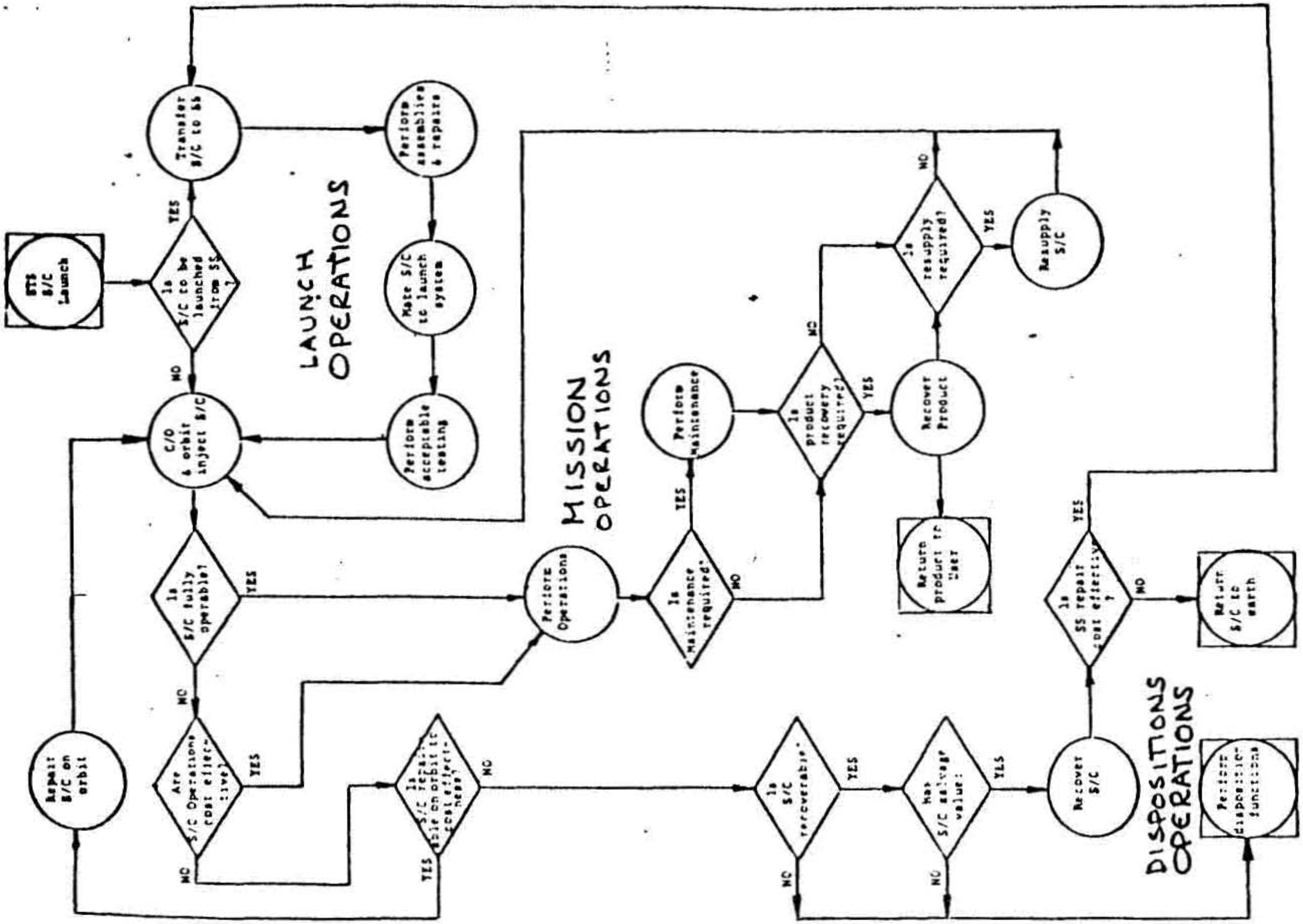
LOGIC DIAGRAM IDENTIFIES S/C DISPOSITIONS IN THE POST 1990 SPACE ENVIRONMENT



SUMMARY LOGIC DIAGRAM ILLUSTRATES INTERFACES BETWEEN LAUNCH, MISSION, & DISPOSITION OPERATIONS

The figure summarizes post 1990 S/C-90 operations in the anticipated space operations environment.

SUMMARY LOGIC DIAGRAM ILLUSTRATES INTERFACES BETWEEN LAUNCH, MISSION, & DISPOSITION OPERATIONS



SPECIALISTS IDENTIFIED IMPACT OF POST 1990 SPACE ENVIRONMENT ON SUBSYSTEMS

Specialists examined the interfaces identified in the logic diagrams and defined functions appropriate to S/C-90 needs. These functions were further analyzed and refined to identify impacts on all subsystem areas.

An example is presented of S/C-90 functions and subsystem impacts for Space Station associated launch activities appropriate to a commercial space processing satellite. A major problem has been recognized in that the electrophoresis processor (EP) must have continuous power to maintain cooling & product separation without electrical discharge during launch handling.

During the contract subsystem impacts due to post 1990 operations were identified for all three S/C-90 concepts.

SPECIALISTS IDENTIFIED IMPACT OF POST 1990 SPACE ENVIRONMENT ON SUBSYSTEMS

POST 1990 SPACECRAFT FUNCTIONS	COMMERCIAL SPACE PROCE NG SATELLITE IMPACTS ON SUBSYS M AREAS					
	ELECTRICAL POWER	STRUCTURES	THERMAL CONTROL	TT&C	DATA MANAGEMENT	SOFTWARE
S/C LAUNCH ACTIVITIES W/SS • DOCK STS TO SS & TRANSFER S/C TO SS SERVICE DOCK USING SS RA	ELEC-PHOR POWER MUST BE MAINTAINED W/O ELECTRICAL DISCHARGES	PROVIDE FOR RA ATTACHMENT & SS PLATFORM GRAPPLE & LOCK	E-P COOLING MUST BE MAINTAINED			TRANSFER-DOCKING SOFTWARE
• PERFORM ASSYS & REPAIRS—CONFIGURE S/C AS REQD	MAINTAIN E-P POWER W/O DISCHARGE. PROVIDE FOR SS POWER UMBILICAL	PROVIDE ACCESSIBLE POWER UMBILICAL SUPPORTS	MAINTAIN E-P COOLING POWER THRU SS UMBILICAL		OUTPUT DATA MANAGEMENT TRU SS UMBILICAL	PROVIDE SUBSYST STATUS TO SS DISPLAYS
• MATE S/C TO PROP UNIT—ATTACH UNIT & OFFLOAD S/C W/SS RA, MAINTAIN UMBILICAL CONNECTION	MAINTAIN SUBSYSTEM & PAYLOAD POWER	PROVIDE PROPUL INTERFACE & AUTOMATIC CLAMPING RELEASE	MAINTAIN E-P COOLING FROM SS UMBILICAL		OUTPUT DATA MANAGE. THRU SS UMBILICAL	PROVIDE SUBSYST STATUS TO SS DISPLAYS. PROVIDE OPERAT SOFTWARE TO SUBSYST FOR C/O

SUMMARY DATA: S/C-90 FUNCTIONS & SUBSYSTEM IMPACTS

The following data illustrates launch operations impacts appropriate to the geosynchronous orbit communications satellite.

SUMMARY DATA: S/C 90 FUNCTIONS & SUBSYSTEM IMPACTS

GEOSYNCHRONOUS ORBIT COMMUNICATIONS SATELLITE

SUB-SYSTEM

S/C FUNCTIONS		ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Launch Activities (W/SS) Dock STS to SS & transfer S/C to SS Service Dock using SS RA	1-1	No stored electrical discharges			Provide for RA attachment & S.S. platform grapple & latch.		Transfer-docking software			
Perform Assemblies & Repairs Configure S/C & perform repairs as required	1-2	Attach power/data umbilical			Provide umbilical support.	Output data management through power/data umbilical.	Provide subsystem & payload status software through umbilical.			Design may include EVA attachment of solar panels, radiators, or antennas.
Mate S/C to Propulsion Unit Attach OTV to off loaded S/C. Maintain umbilical power/data connect through OTV to SS	1-3	Provision to obtain from OTV.			Provide OTV interface.	Input to OTV to SS displays.	Provide subsystems software			
Perform acceptance testing. Display S/C status at S.S. through OTV umbilical. Thermal-vac testing can be cost effective here.	1-4	Provide TV & subsystem test.	Provide TV & subsystem test			Provide TV & subsystem test.	Provide test software.	Provide TV & subsystem test	Provide TV & subsystem test	
C/O & Orbit Inject w/OTV Disconnect OTV umbilical. Operate subsystems as required. Housekeeping readout, Orbit inject, deploy & monitor operations.	1-5	Provide power to all subsystems & payload w/OTV until operations. Power on subsystems.	OTV to orbit then inject using S/C GN&C, deploy & separate.	Use OTV except GN&C RCS	Provide OTV disconnect. Provide automatic umbilical disconnect.	Through OTV until deployment, then through TT&C	Provide operations, launch, deploy, & status software.	Maintain S/C thermal needs at all times.	Initiate operations after OTV separation. Transmit to OTV & TDRSS. EVA unfurl large antenna.	EVA unfurlable large antenna
S/C Launch Activities (W/STS) C/O & Orbit Inject. Disconnect umbilical from S/C to STS. Operate required subsystems. Housekeeping readout. Orbit inject, deploy & monitor operations	1-6	Provide subsystem power.	Activate GN&C system after separation from STS.	Activate propulsion system, fire on command.	Automatic umbilical, & latches released Design unfurlable large antenna	Data management stream to TT&C after separation from STS.	Provide software launch, deploy, inject, & status	Maintain S/C thermal needs	Initiate operations after S/C-STS separation through STS & TDRSS.	

POST 1990 SCENARIO COMPONENTS:

1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS, RESEARCH, TEST, REPAIR, LAUNCH, & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSEABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

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The following data illustrates mission & disposition operations impacts appropriate to the geosynchronous communications satellite.

SUMMARY DATA: S/C-90 FUNCTIONS & SUBSYSTEM IMPACTS

GEOSYNCHRONOUS ORBIT COMMUNICATIONS SATELLITE

SUB-SYSTEMS

S/C FUNCTIONS		ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Operations Perform Communications Operations	1-7	Operations	Operations	Operations	Operations	Operations	Operations	Operations	Operations	Operations
S/C Orbital Repair Dock OTV to S/C, repair on orbit using EVA	1-8	Remote turnoff after docking	Maintain attitude control to facilitate docking. Turn off after docking.		Provide OTV docking adaptor.	Status & housekeeping to OTV on demand.	Provide repair & docking software.	Provide remote turnoff coincident with payload turnoff.	Remote turnoff after docking	
C/O & Orbit Inject	1-9	Power all subsystems.	Activate after OTV release.		Provide automatic OTV docking release.	After release by OTV, output to TT&C.	Provide release & injection software.	Provide thermal PL & subsystem controls.	Provide status & housekeeping transmissions & receive commands from OTV & TDRSS.	
Perform Maintenance	1-10	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.
Recover Product Resupply	1-11	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.
S/C Dispositions Recover S/C for earth return Dock OTV to S/C, deorbit to STS & transfer to STS	1-12	Remote turnoff after docking	Maintain attitude control to facilitate docking. Turn off after docking.		Provide OTV docking adaptor. Provide docking adaptor for STS RA & latches for cradle tie-down.	Status & housekeeping to OTV on demand. Turn off RA transfer to STS.	Provide transfer software. Provide docking software.	Provide remote turnoff coincident with payload turnoff.	Remote turnoff after docking	May have to use EVA TO remove large antenna.
S/C Disposition Recover S/C for SS Repair Dock OTV to S/C & deorbit to SS	1-13	Remote turnoff after docking.	Maintain attitude control to facilitate docking. Turn off after docking		Provide OTV docking adaptor	Status & housekeeping to OTV on demand.	Provide docking software.	Provide remote turnoff coincident with payload turnoff	Remote turnoff after docking.	
S/C transfer to SS by OTV Dock OTV to SS & transfer S/C to SS Service Dock using SS RA.	1-14	No stored electrical discharges			Provide for RA attachment & S.S. platform grapple & lock.		Transfer-docking software			May have problems with transfer of large antenna.

POST 1990 SCENARIO COMPONENTS:
1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS, RESEARCH, TEST, REPAIR, LAUNCH, & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSEABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

The following data illustrates launch operations impacts appropriate to the advanced navigation satellite.

SUMMARY DATA: S/C-90 FUNCTIONS & SUBSYSTEM IMPACTS

ADVANCED NAVIGATION SATELLITE

SUB-SYSTEM

S/C FUNCTIONS	ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Launch Activities W/SS Dock SIS to SS & transfer S/C to SS Service Dock using SS RA 2-1	Power for thermal control of payload clock must be maintained. No electrical discharges.			Provide for RA attachment & SS platform grapple & lock.		Transfer/ docking software	Thermal control of clock must be maintained.		
Perform Assemblies & Repairs 2-2	Processor power must be maintained. No electrical discharges. Provide for SS power umbilical.			Provide accessable power umbilical supports.	Output data management through SS umbilical.	Provide subsystems status software to SS displays.	Thermal control of clock must be maintained. Cooling power from SS umbilical.		Design may include EVA attachment of ancillary equipment (antennas, solar panels, radiators).
Mate S/C to Propulsion Unit Attach OTV to off-loaded S/C Maintain umbilical power/data Connect through OTV from SS. 2-3	Maintain subsystem & payload power.			Provide propulsion connecting post & automatic clamping release.	Output data management through SS umbilical.	Provide subsystems status software to SS displays. Provide subsystems software for ops.			
Perform Acceptance Testing Display S/C status at SS through OTV umbilical. Thermal-vac testing can be cost effective here. 2-4	Provide TV & subsystem test.	Provide TV & subsystem test.			Provide TV & subsystem test. Output data management through SS umbilical.	(GN&C) Provide test & display software. Provide operations software (GN&C)	Provide TV & subsystem test.	Provide TV & subsystem test.	
C/O & Orbit Inject W/OTV Disconnect OTV umbilical Operate subsystems as reqd Housekeeping readout, Orbit inject, display, & Monitor operations 2-5	Provide power as required to PL & subsystems.	Provide GN&C operations.	Provide propulsion operations.	Provide automatic umbilical disconnect.	Provide subsystem & payload housekeeping data to TT&C	Provide operations, launch, injection & status software.	Provide thermal control operations.	Activate TT&C transmit status & confirmations of commands received to SS & TDRSS	
S/C Launch Activities W/STS only C/O & Orbital Inject S/C Disconnect umbilical to S/C from STS Operate required subsystems Housekeeping readout Orbital inject, display & monitor operations. 2-6	Provide power as required to PL & subsystems	Provide GN&C operations.	Provide propulsion operations.		Provide subsystem & payload housekeeping data to TT&C.	Provide operations, launch, injection & status software.	Provide thermal control operations.	Activate TT&C & transmit status & confirmations of commands to SS, TDRSS, & ground.	

POST 1990 SCENARIO COMPONENTS:

1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS, RESEARCH, TEST, REPAIR, LAUNCH, & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSEABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

SUMMARY DATA: S/C-90 FUNCTIONS & SUBSYSTEM IMPACTS

The following data illustrates mission & disposition operations appropriate to the advanced navigation satellite.

SUMMARY DATA: S/C 90 FUNCTIONS & SUBSYSTEM IMPACTS

ADVANCED NAVIGATION SATELLITE

SUB-SYSTEM

S/C FUNCTIONS	ELECTRICAL POWER	G&LS	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Operations Perform navigation operations 2-7	Operations	Operations	Shutdown after STS deployment		Operations	Operations	Operations	Operations	Operations
S/C Orbital Repair Dock OTV to S/C repair on orbit using EVA 2-8	Maintain power to thermal subsystem after docking	Maintain attitude control to facilitate docking. Turn off after docking.		Provide OTV docking adaptor.	Maintain thermal system output. Status & housekeeping to OTV on demand.	Provide repair & docking software/	Maintain clock thermal control. No electrical discharges.	Remote turnoff after docking.	
C/O & Orbit Inject 2-9	Power all subsystems.	Activate after OTV release.		Provide automatic OTV docking release.	After release by OTV, output to TT&C.	Provide release & injection software	Provide thermal PL & subsystem controls.	Provide status & housekeeping transmissions & receive commands from OTV & TDRSS.	
Perform Maintenance 2-10	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.
Recover Product Resupply 2-11	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.
S/C Dispositions Recover S/C for earth return Dock OTV to S/C, deorbit to STS & transfer to STS 2-12	Maintain power to thermal subsystem after docking.	Maintain attitude control to facilitate docking. Turn off after docking.		Provide OTV docking adaptor. Provide docking adaptor for STS RA & latches for cradle tie-down.	Status & housekeeping to OTV on demand. Turn off after RA transfer to STS except for thermal subsystem	Provide docking & transfer software.	Maintain clock thermal control. No electrical discharges .	Remote turnoff after docking.	
S/C Disposition Recover S/C for SS repair. Dock OTV to S/C & deorbit to SS 2-13	Maintain power to thermal subsystem after docking.	Maintain attitude control to facilitate docking. Turn off after docking.		Provide OTV docking adaptor.	Status & housekeeping to OTV on demand. Maintain thermal system output.	Provide docking & transfer software.	Maintain clock thermal control. No electrical discharges.	Remote turnoff after docking	
S/C transfer to SS by OTV Dock OTV to SS & transfer S/C to SS service dock using SS RA 2-14	Provide power to thermal coolant clock subsystem. No stored electrical discharges			Provide for RA attachment & SS platform grapple & lock.		Transfer-docking software	Provide clock thermal control.		

POST 1990 SCENARIO COMPONENTS:
1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS, RESEARCH, TEST, REPAIR, LAUNCH & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

SUMMARY DATA: S/C-90 FUNCTIONS & SUBSYSTEM NEEDS

The following data illustrates launch operations appropriate to the commercial space processing satellite.

SUMMARY DATA: S/C 90 FUNCTIONS & SUBSYSTEM IMPACTS

COMMERCIAL SPACE PROCESSING SATELLITE

SUB-SYSTEM

S/C FUNCTIONS		ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Launch Activities (w/SS) Dock STS to SS & transfer S/C to SS service dock using SS RA	3-1	Processor power must be maintained. No electrical discharges.			Provide for RA attachment, and SS platform grapple & lock		Transfer-Docking Software	Processor cooling must be maintained		
Perform Assemblies & Repairs. Configure S/C & perform repairs as required.	3-2	Processor power must be maintained. No electrical discharges. Provide for SS power umbilical.			Provide accessible power umbilical supports.	Output data management through SS umbilical.	Provide subsystem status software to SS displays.	Processor cooling must be maintained. Cooling power from SS umbilical.		Design may include EVA attachment of ancillary equipments (antennas, solar panels, radiators).
Mate S/C to Propulsion Unit Attach propulsion unit & offload S/C with SS RA. Maintain umbilical connection.	3-3	Maintain subsystem & payload power.	Maintain S/C attitude control.	Do not provide power input to propulsion subsystems.	Provide propulsion connecting port & automatic clamping release.	Output data management through SS umbilical.	Provide subsystem status software to SS displays. Provide subsystems S/W for operations (GN&C)	Processor cooling must be maintained. Cooling power from SS umbilical.		
Perform acceptance testing Display S/C status at SS through umbilical. Note: Thermal-vac testing can be cost effective here.	3-4	Provide TV & subsystem test.	Provide TV & subsystem test.			Provide TV & subsystem test. Output data management through SS umbilical.	Provide test & display software. Provide operations software (GN&C).	Provide TV & subsystem test.	Provide TV & subsystem test.	
C/O & Orbit Inject Disconnect umbilical Operate subsystems as required Housekeeping readout Orbit inject & monitor to operations	3-5	Provide power as required to PL & subsystems.	Provide GN&C operations.	Provide propulsion operations	Provide automatic umbilical disconnect.	Provide subsystem & payload housekeeping data to TT&C.	Provide operations, launch, injection & status software.	Provide thermal control operations.	Activate TT&C transmit status & confirmations of commands received to SS & TDRSS.	
S/C Launch Activities (w/STS only) C/O & orbit inject Disconnect umbilical Operate required subsystems Housekeeping readout Orbit inject & monitor operations	3-6	Provide power as required to PL & subsystems		Provide propulsion operations			Provide operations, launch, injection & status software.	Provide thermal control operations.	Activate TT&C & transmit status & confirmations of commands to SS, TDRSS & ground.	

POST 1990 SCENARIO COMPONENTS:

1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS RESEARCH, TEST, REPAIR, LAUNCH & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSABLE
4. TDRSS-AS CURRENT
5. MMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

The following data illustrates mission operations appropriate to the commercial space processing satellite.

SUMMARY DATA: S/C 90 FUNCTIONS & SUBSYSTEM IMPACTS

COMMERCIAL SPACE PROCESSING SATELLITE

SUB-SYSTEM

S/C FUNCTIONS	ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Operations Perform electrophoresis Operations 3-7	Operations	Operations	Shutdown after deployment		Operations	Operations	Operations	Operations	
S/C Orbital Repair w/STS Deorbit S/C, Co-orbit STS, connect STS RA. Place in & repair in STS cradle 3-8	Shutdown power remotely except to PL & attitude control. No electrical discharges	Remote shutdown except for attitude control Full shutdown after capture.	Restart & deorbit. Complete shutdown after deorbit.	Provide for RMU interface	Status readouts to TT&C until S/C capture.	Provide repair software	Maintain payload cooling	Remote shutdown after S/C capture.	Packaging will accommodate EVA repairs.
C/O & orbit inject Disconnect STS subsystems Operate S/C subsystems as reqd. Housekeeping readout. Orbit inject & monitor operations 3-9	Provide power as reqd. to payload & subsystems	Provide GN&C operations.	Provide propulsion operations by restart of engine & shutdown after deployment.	Provide automatic cradle clamp releases.	Provide payload & subsystem housekeeping & operations data to TT&C.	Provide operations launch, injection & status software.	Provide thermal control operations.	Reactivate TT&C for operations & xmet/receive sequencing of commands & status.	
Perform Maintenance 3-10	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.	Not reqd.
Recover Product & Resupply Deorbit S/C, Coorbit STS, connect STS RA & support S/C in STS cradle. Transfer product to STS. Replace with new cannister. Replace expended subsystem components. 3-11	Maintain PL power until product transfer. Restart for resupply. No electrical discharges	Remote shutdown except attitude control after deorbit. Full shutdown after capture.	Restart & deorbit. Shutdown for capture. No electrical power to this subsystem		Data management stream to STS after cradle attach.	Product recovery & resupply software	Maintain thermal control of payload until transfer, then restart after resupply of cannister.	Shutdown TT&C after capture.	Packaging will accommodate EVA resupply.
C/O & orbit inject See 2-3 above 3-12	See 3-9	See 3-9	See 3-9	See 3-9	See 3-9	See 3-9	See 3-9	See 3-9	See 3-9

POST 1990 SCENARIO COMPONENTS:
1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS RESEARCH, TEST, REPAIR, LAUNCH, & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

The following data illustrates disposition operations appropriate to the commercial space processing satellite.

SUMMARY DATA: S/C 90 FUNCTIONS & SUBSYSTEM IMPACTS

COMMERCIAL SPACE PROCESSING SATELLITE

SUB-SYSTEM

S/C FUNCTIONS		ELECTRICAL POWER	GN&C	PROPULSION	STRUCTURES	DATA MANAGEMENT	SOFTWARE	THERMAL CONTROL	TT&C	PACKAGING
S/C Disposition with STS Recover S/C for STS return to earth. Deorbit S/C, coorbit STS, connect STS RA, & support S/C in STS cradle.	3-13	Maintain payload power.	Maintain attitude control & deorbit until capture. Then shutdown.	Restart & deorbit to STS. Complete shutdown. No electrical power.	Provide umbilical attach point.	Provide output through STS umbilical for status.	Provide software for status.	Maintain payload cooling.	Shutdown after capture.	
S/C Disposition (with STS) Recover S/C for SS repair. Deorbit S/C, coorbit STS, connect STS RA, support S/C in STS cradle, transfer process cannister.	3-14	Shutdown subsystem after cradle attach.	Maintain attitude control & deorbit until capture. Then shutdown.	Restart & deorbit to STS. Complete shutdown. No electrical power.		Shutdown subsystem after cradle attach.	Shutdown subsystem after cradle attach.	Shutdown subsystem after cradle attach.	Shutdown after capture.	May be necessary to EVA remove solar panels, radiators & antennas.
S/C Disposition (with STS) Dock STS to SS & transfer S/C to SS service dock using SS RA (See 1-1)	3-15	See 3-1	See 3-1	See 3-1	See 3-1	See 3-1	See 3-1	See 3-1	See 3-1	See 3-1

POST 1990 SCENARIO COMPONENTS:
1. STS WITH GREATER CARGO LOAD CAPACITY
2. SPACE STATION, SS-MANNED WITH DEDICATED MODULES & ORBITING CLUSTERS. RESEARCH, TEST, REPAIR, LAUNCH, & OPERATIONS
3. OTV-MANNED, TO GEOSYNCH & REUSABLE
4. TDRSS-AS CURRENT
5. RMU-REMOTE MANEUVERING UNIT, MANNED
6. RA-ROBOT ARM

The figure summarizes mechanical impacts upon the structures subsystem. Most impacts are concerned with handling & transfer among STS, Space Station and OTV, and involve design requirements necessary to assure ease of repair, assembly, checkout & test on orbit.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

	SUMMARY IMPACT ON SUBSYSTEM		
SUBSYSTEM AREA	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
STRUCTURAL SUBSYSTEM		• PROVIDE STANDARDIZED INTERFACE: 1. WITH ROBOT ARMS OF SS, OTV, AND STS 2. GRAPPLE AND LATCH WITH SS AND STS 3. RMU AND OTV DOCKING • EXTERNAL UMBILICAL SUPPORT BRACKETS AND AUTOMATIC RELEASES • UNFURLABLE LARGE ANTENNA FOR COMSAT • DETACHABLE ANTENNAS, RADIATORS AND SOLAR PANELS • ASSURE EASE OF ON ORBIT AND SS REPAIR/ REPLACEMENT OF COMPONENTS	

Electrical power must be maintained to the electrophoresis unit & navigation clock without interference with on orbit operations. Software coordinates test & repair activities with power needs.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

	SUMMARY IMPACT ON SUBSYSTEM		
SUBSYSTEM AREA	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
ELECTRICAL POWER	• DURING SERVICING PROVIDE AUXILIARY POWER SOURCE TO: 1. MAINTAIN MPS SPACE PROCESSOR AND COOLANT 2. MAINTAIN AGPS CLOCK THERMAL SUBSYSTEM • ASSURE NO ELECTRICAL DISCHARGES EVEN IN AREAS WHERE POWER CONTINUALLY APPLIED DURING SERVICING • EXTERNAL POWER UMBILICAL • INTERNAL/EXTERNAL TEST POINTS	• SUPPORT/ATTACH MECH FOR POWER UMBILICAL	• REMOTE COMMANDED SELECTABLE CIRCUIT POWER SHUTDOWN

Software is essential to nearly all S/C-90 on orbit servicing, repair, test, and operations.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

	SUMMARY IMPACT ON SUBSYSTEM		
SUBSYSTEM AREA	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
SOFTWARE			• DOCKING TO SS, STS, AND OTV • SELECTIVE SUB-SYSTEM HEALTH AND STATUS TO DISPLAYS • OPERATIONS, LAUNCH, AND INJECTION • REPAIR AND TESTING • MPS PRODUCT RECOVERY AND RE-SUPPLY • STATUS SIGNAL OUTPUT ROUTING • REMOTE COMMANDS • REMOTE CHANGES / REPROGRAM

Thermal controls are needed to cool the electrophoresis unit & navigation clock. Software coordinates cooling & power needs during operations.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

SUBSYSTEM AREA	SUMMARY IMPACT ON SUBSYSTEM		
	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
THERMAL CONTROL	• INTERNAL/ EXTERNAL TEST POINTS • ASSURE NO ELECTRICAL DISCHARGES IN POWER ON AREAS BEING SERVICED	• ACCESSIBLE TEST PANEL	• INDEPENDENT MAINTENANCE OF MPS PROCESSOR COOLANT • INDEPENDENT MAINTENANCE OF AGPS NAVIGATION CLOCK COOLANT • SELECTIVE SUBSYSTEM COMPONENT SHUTDOWN AND OPERATIONS
PACKAGING		• SUBSYSTEM ACCESS FOR SERVICE THRU MLI • ASSURE ON ORBIT REPAIR, SERVICE, TEST, AND RESUPPLY WITH HANDABLE PACKAGING • EVA REMOVAL/ATTACH OF ATENNAS, SOLAR PANELS, AND THERMAL RADIATORS	

Excepting mission operations, TT&C will be conducted through umbilicals to the service S/C. Software is necessary for status reporting.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

SUBSYSTEM AREA	SUMMARY IMPACT ON SUBSYSTEM		
	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
TT&C	• PROVIDE INTERNAL/EXTERNAL TEST POINTS FOR TESTING • PROVIDE TT&C UMBILICAL	• PROVIDE ACCESSIBLE TEST PANEL • PROVIDE TT&C UMBILICAL ATTACH AND AUTOMATIC RELEASE	• STANDARDIZE COMMO INTERFACE WITH SS, OTV, STS, AND TDRSS • REMOTE OPERATIONS AND SHUTDOWN

Space Station will be utilized for service & testing of S/C and make necessary software for subsystem checkout.

ELECTRICAL, MECHANICAL, AND SOFTWARE SUBSYSTEM NEEDS IN POST 1990 SPACE OPERATIONS ENVIRONMENT

	SUMMARY IMPACT ON SUBSYSTEM		
SUBSYSTEM AREA	ELECTRICAL-ELECTRONIC	MECHANICAL	SOFTWARE
GN&C	• PROVIDE INTERNAL/EXTERNAL TEST POINTS TO FACILITATE ON ORBIT TESTING	• PROVIDE ACCESSIBLE TEST PANEL	• REMOTE OPERATIONS TO FACILITATE DOCKING SERVICE
PROPULSION	• PROVIDE INTERNAL/EXTERNAL TEST POINTS	• STANDARD INTERFACE WITH OTV • PROVIDE ACCESSIBLE TEST PANEL	• REMOTE COMMAND OVER-RIDE, SHUT-DOWN AND OPERATIONS
DATA MANAGEMENT	• PROVIDE INTERNAL/EXTERNAL TEST POINTS • PROVIDE EXTERNAL DATA STREAM UMBILICAL	• STANDARD INTERFACE WITH OTV • PROVIDE ACCESSIBLE TEST PANEL • PROVIDE DATA STREAM UMBILICAL SUPPORT AND ATTACH MECHANISM	• SELECTIVE HEALTH AND STATUS READOUTS THROUGH TT&C OR DATA UMBILICAL ON COMMAND

APPENDIX B

SPACECRAFT 90 SURVIVABILITY

In a companion study to the work of this contract, an effort supported by Rockwell's Satellite Systems Division discretionary funds examined the effect of radiation environment on the spacecraft configuration. This Appendix outlines the results of that study for those readers who may be interested in that aspects of an advanced spacecraft design program.

The ability of the Spacecraft 90 design to survive for 10 years in space has been evaluated. Three circular earth orbits have been selected for S/C 90 missions; Low Earth Orbit (LEO) at 28.5^0 inclination, the Global Position Spacecraft (GPS) orbit at 55^o inclination, and Geosynchronous Earth Orbit (GEO) at 0^o inclination. For each of these 3 orbits, the environments considered were the natural nuclear radiations (Van Allen Belts, solar flare radiation events), trapped fission electrons (assuming a Starfish-type nuclear weapon detonation in space) and solid objects in space (cometary meteoroids and earth orbiting space debris). The major effects of these environments will be on the semiconductor electronics located in boxes around the equator of the spacecraft. The box walls are $\sim$1 gm/cm^2 (146 mils of Al equivalent) in the thickness, and reasonably hard (radiation resistant) electronics can tolerate 10^5 rads of total dose.

SPACECRAFT SURVIVABILITY

THREE ORBITS CONSIDERED (ALL CIRCULAR)

- LEO ($\leq$600 NMi, 28^{0} INCLINATION)
- GPS (10,900 NMi, 55^{0} INCLINATION)
- GEO (19,323 NMi, 0^{0} INCLINATION)

ENVIRONMENTS CONSIDERED

- NATURAL NUCLEAR RADIATION
- TRAPPED FISSION ELECTRONS
- OBJECTS IN SPACE (METEOROIDS, DEBRIS)

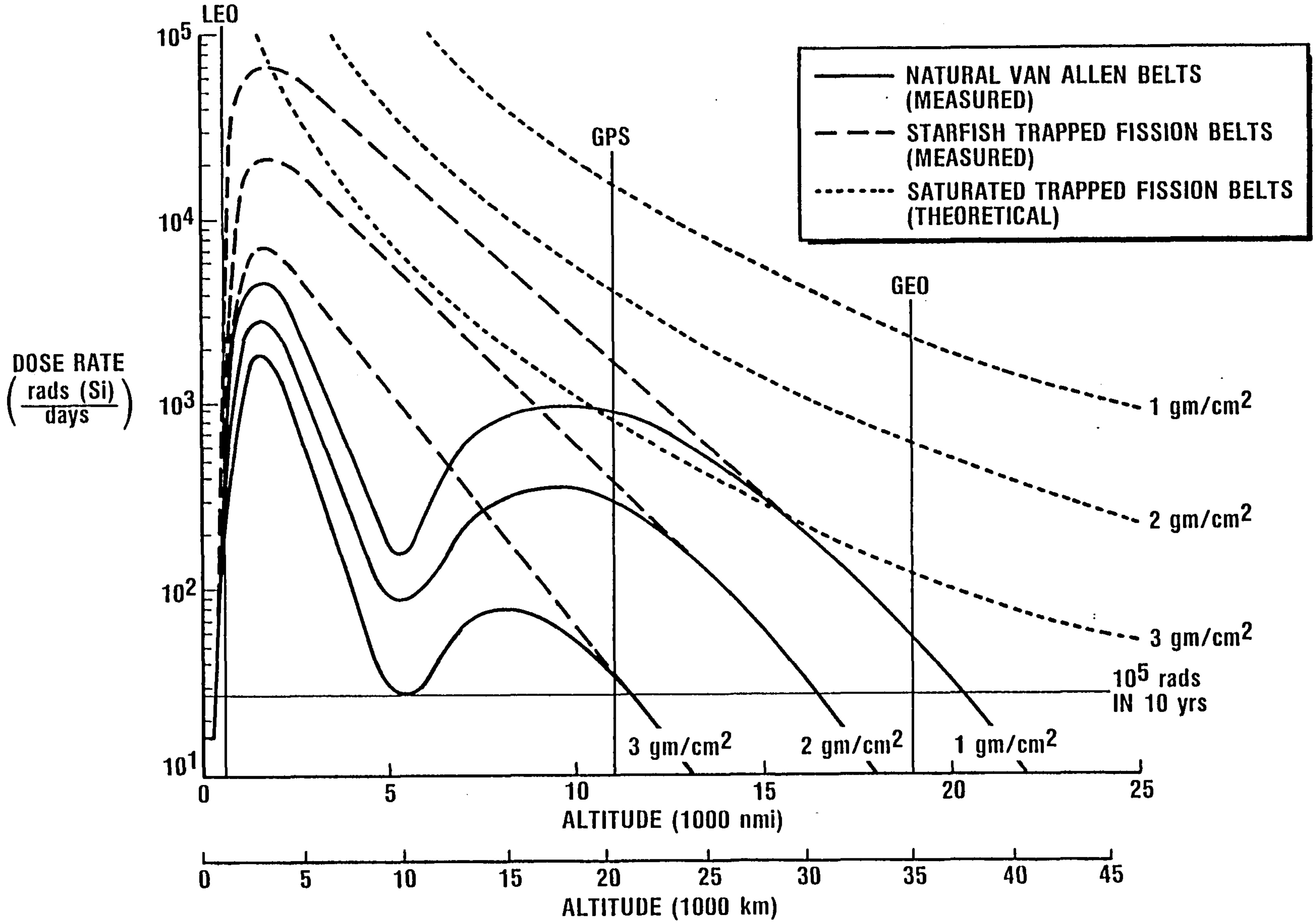
SPACECRAFT ELECTRONICS CONSIDERED

- $\geq$1 GM/CM^{2} SHIELDING
- $\sim 10^{5}$ RADS TOTAL DOSE TOLERANCE

EARTH'S VAN ALLEN BELTS VS ALTITUDE AT 0^{o}

The geomagnetically trapped earth's Van Allen belts are composed of electrons and protons. While the fluxes of these elctrons and protons exhibit the double-humped spatial distribution with altitude, the average energies of the electrons and protons decrease monotonically with altitude. Because of this, increasing the spacecraft shield thickness at high altitudes decreases the dose rate more than at low altitudes. For electronics which can stand 10^5 rads/10 years $\gtrsim$ 27 rads/day, the shielding required varies considerably with altitude. For low altitiude orbits ($\lesssim$ 600 NM) and for geosynchronous orbits, 1 gm/cm^2 will be adequate, but for GPS altitudes even the natural Van Allen belts will require more than 1 gm/cm^2 if 27 rads/day is to be achieved. If Starfish-type trapped fission electrons or saturated belt trapped fission electrons are present, the shielding required will be considerably greater.

EARTH'S VAN ALLEN BELTS VERSUS ALTITUDE AT 0°



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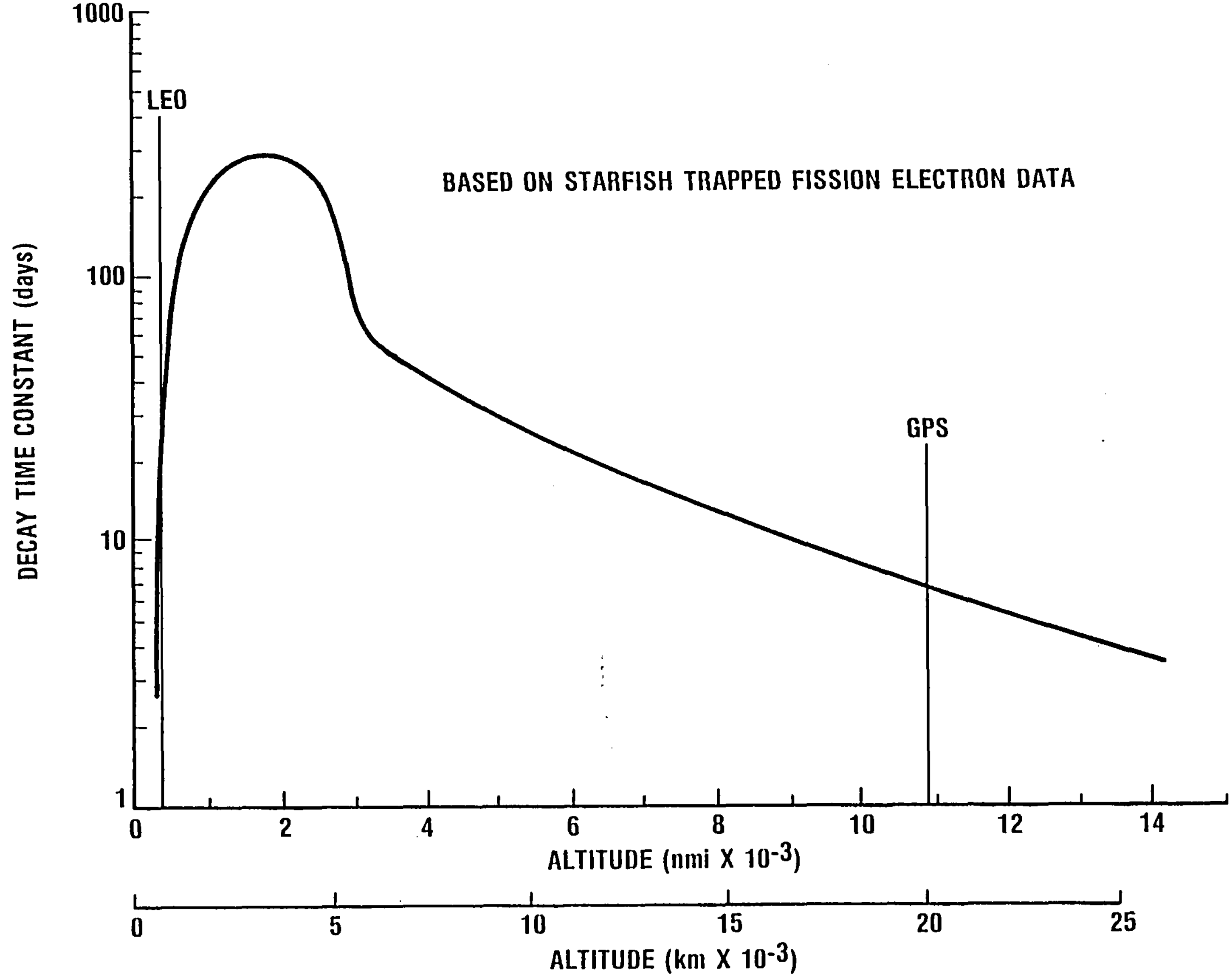
DECAY CONSTANT VS ALTITUDE FOR TRAPPED FISSION ELECTRONS

Unlike the natural Van Allen belts, the geomagnetically trapped fission electrons (produced by a nuclear weapon detonation in space) are not constant with time. Because they lack a continuous source (which the natural Van Allen belts have) the trapped fission electron flux decreases quasi-exponentally with time. The decay content (time for the fission electron flux to decrease a factor of e) observed after the Starfish detonation in 1962 varies as shown as a function of altitude. For low altitude orbits, the decay constant varied from ~6 days (a) 300NMi to ~100 days (a) 600NMi. For GPS and GEO orbits, the decay constants were 6 days. Consequently, the time integrated electron fluences were 3×10^{14} e/cm^2 (GPS orbit) and 1×10^{14} e/cm^2 (GEO orbit). For LEO, the trapped fission electron fluences were even larger.

DECAY CONSTANT VERSUS ALTITUDE FOR TRAPPED FISSION ELECTRON



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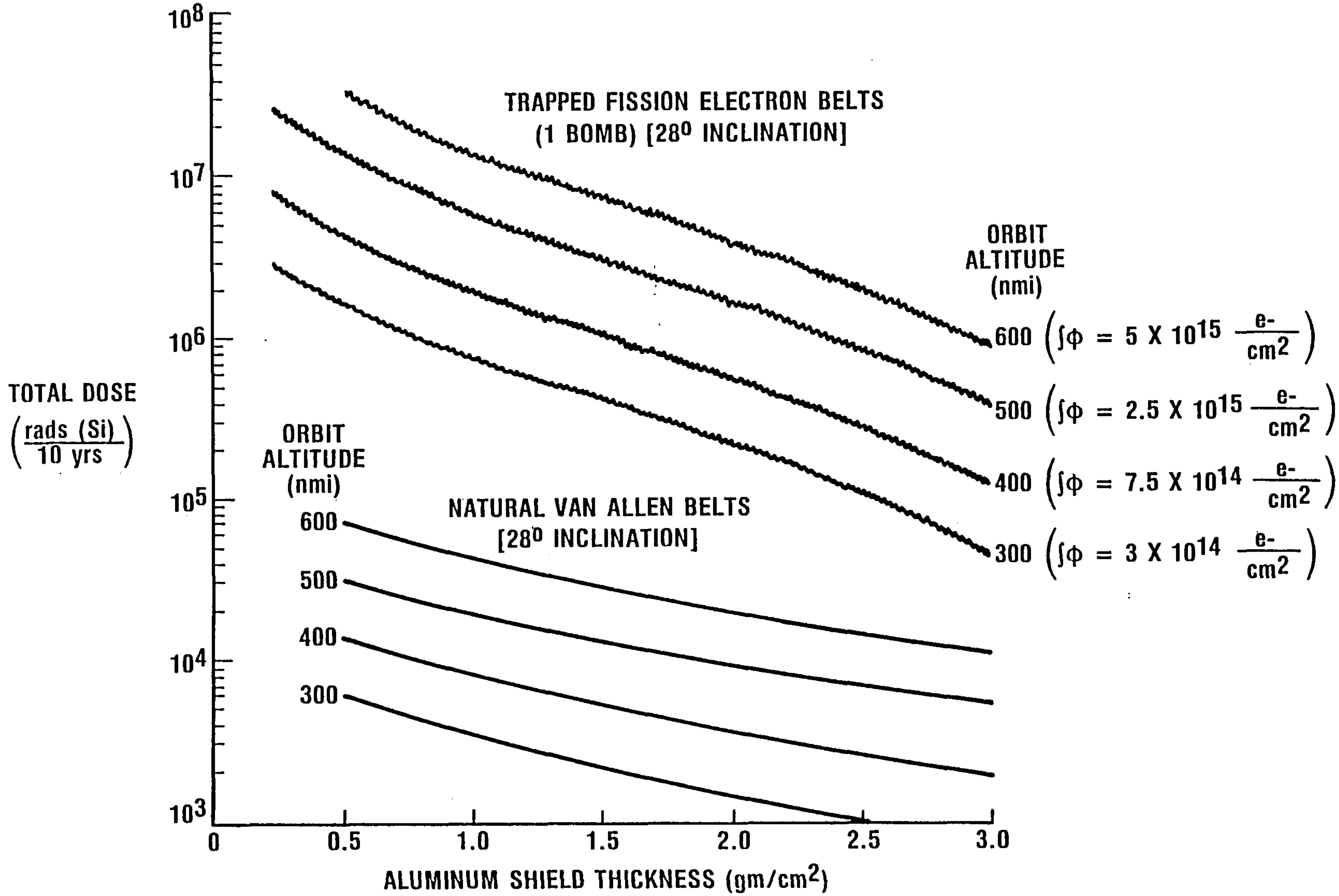
This graph shows the 10 year mission dose in low earth orbits as functions of orbit altitude and shielding. The doses are in rads (silicon) since essentially all of the spacecraft semiconductor components will be made of silicon. The bottom curves show the mission doses due to the natural Van Allen belts; the upper curves show the mission doses if Starfish-type trapped fission electrons are present. It has been assumed that the initial trapped fission electron fluxes are 5×10^8 e/cm^2-sec and that the nuclear weapon detonation which produced the trapped fission electron belt took place at least a year before the end of the mission. The mission doses are twice these at the same altitudes at 0^o inclination because of the South Atlantic anomaly at 500 NMi altitude, at lower altitudes the ratio is larger. It is seen that 1 gm/cm^2 shielding is plenty for the natural Van Allen belts but quite inadequate if trapped fission electrons are present.

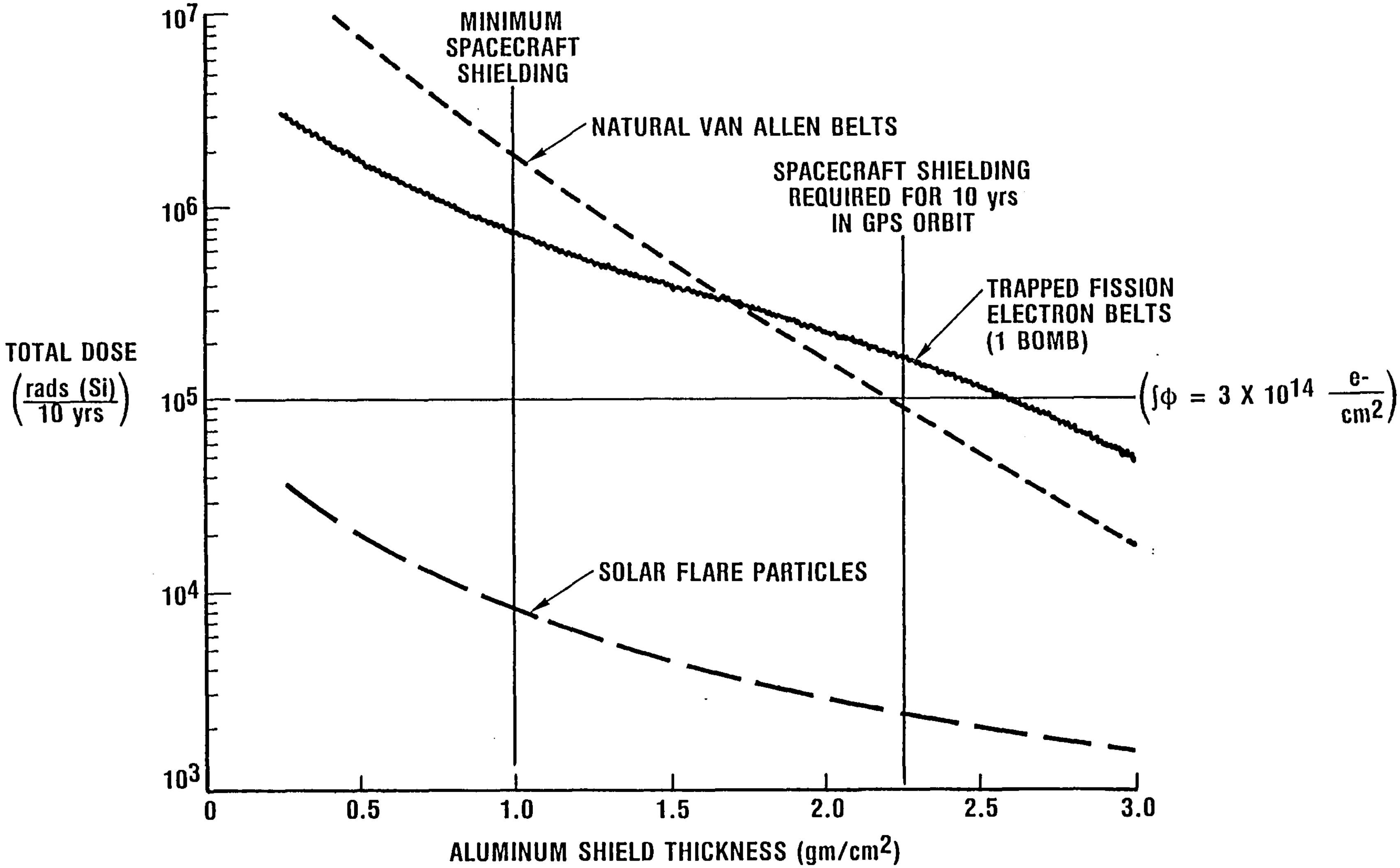
NUCLEAR RADIATION ENVIRONMENTS FOR LEO ORBITS



The 55^{o} inclined GPS orbits have natural Van Allen and trapped fission electron environments which are 20% of these at 0^{o} inclination orbits at the same altitude. Even so, 1 gm/cm^2 of shielding is not sufficient to protect electronics which can tolerate 10^5 rads for 10 years in this orbit. At this altitude, the energies of the Van Allen protons are so low that 0.1 gm/cm^2 will stop them, so only the electrons in the Van Allen belts are of consequence. Because of the short decay constant (~ 6 days) the trapped fission electron dose due to a Starfish-type event is comparable to the natural Van Allen belt mission dose. At this altitude, the earth's magnetic field no longer excludes many of the protons and alpha particles of a solar flare radiation event, so 1 NASA nuclear solar flare event/year was used to generate the bottom curve. However, the natural and trapped fission electron environments dominate.

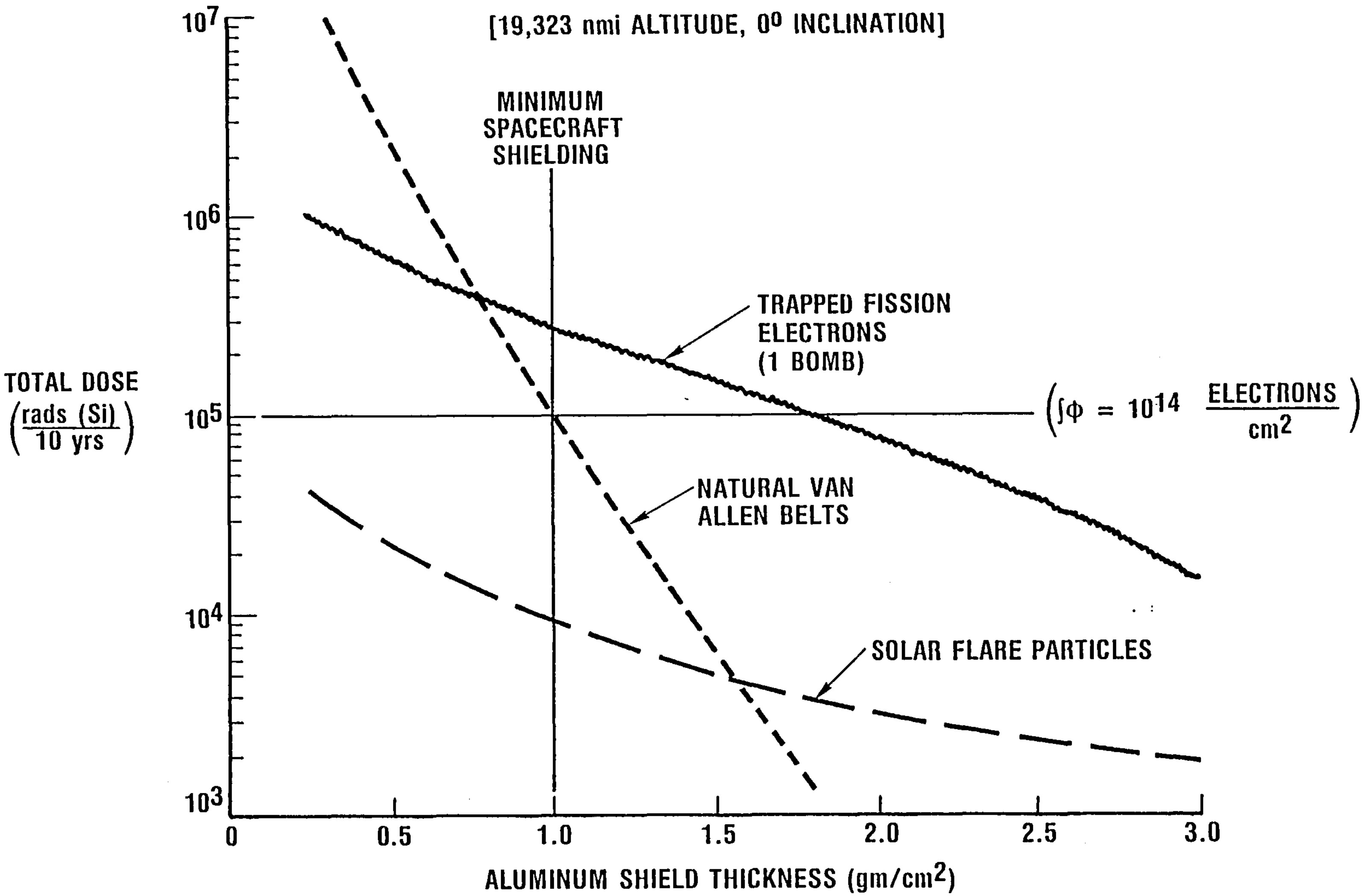
NUCLEAR RADIATION ENVIRONMENT FOR GPS ORBIT

[10,900 nmi ALTITUDE, 55^{0} INCLINATION, CIRCULATOR ORBIT]



The 10 year mission doses for geosynchronous earth orbit as a function of shield thickness are shown in the graph. As for the GPS orbit, the Van Allen belt protons are readily stopped by <0.1 gm/cm^2 and the solar flare particles are important only in the absence of trapped fission electrons. For the 1 gm/cm^2 which Spacecraft 90 has for electronic components dose to the exposed surfaces of the electronics boxes, the mission dose is 10^5 rads (which carefully selected components and carefully designed circuits can withstand). As at other altitudes, if a Starfish-type weapon detonation takes place, more shielding will be required if the mission duration is to be 10 years.

NUCLEAR RADIATION ENVIRONMENT FOR GEO ORBIT



There are several technologies used for making semiconductor electronics components - n doped metal oxide silicon (NMOS) p doped metal oxide silicon (CMOS), complementary metal oxide silicon/silicon on sapphire (CMOS/SOS), etc. Each technology has an approximate component total dose hardness limit ($\pm$ a factor of $\sim$ 3), that hardness being listed in this table. Generally, the small, low power devices are less tolerant of total dose than are larger high power devices. A secondary benefit of large, high power devices is that they are less susceptable to single event upset due to cosmic ray particles. It can be seen from this table that circuits hard to 10^5 rads can be achieved if reasonable care is taken in component selection (circuits cannot be harder than the devices used in them, and may be softer).

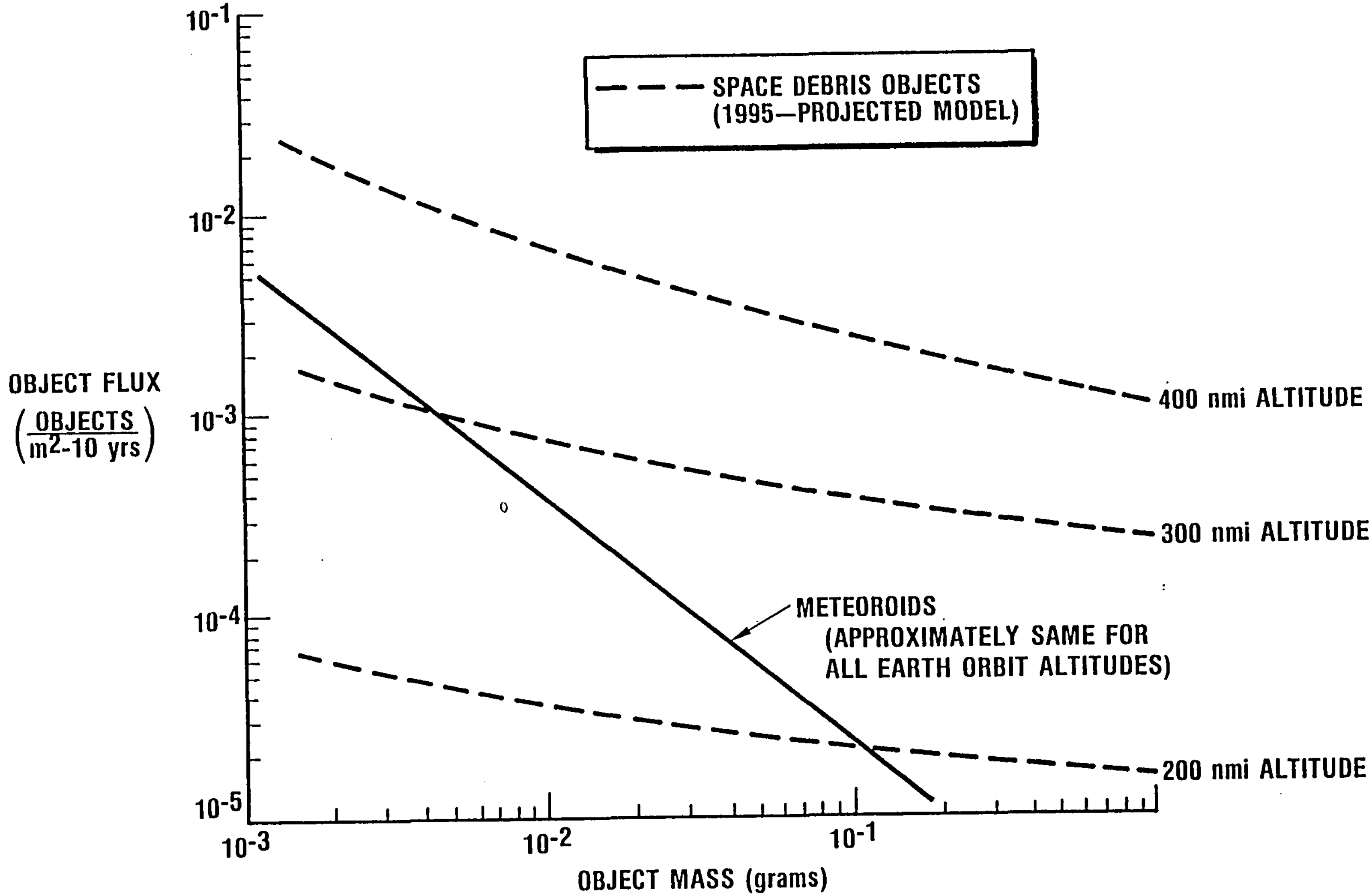
TOTAL DOSE LIMITS FOR ELECTRONICS

ELECTRONICS TECHNOLOGY	APPROXIMATE TOTAL DOSE LIMIT (RADS)
NMOS	1×10^4
PMOS	1×10^5
CMOS	1×10^5
PMOS/SOS, CMOS/SOS	3×10^5
FET	1×10^5
LOW POWER T^2L	1×10^5
SCHOTTKY T^2L	2×10^5
HARDENED T^2L	3×10^6
I^2L	3×10^5
E^2L	5×10^5

In addition to nuclear radiation, there is another environment which must be considered in the Spacecraft 90 design; space debris. Space debris consists of man-made objects in earth orbit; everything from spent rocket casings to pieces of spacecraft which resulted from USSR killer satellite tests. Kessler has used the present known debris object flux to project what the debris object flux is expected to be in 1995. For comparison purposes, this projected debris object flux (which is important only for low earth altitudes orbits) is shown with the naturally occuring meteoroid flux (which is approximately the same at all altitudes). It will be noted that for objects larger than a milligram, the 1995 projected debris object flux exceeds the meteoroid object flux for altitudes $\gtrsim$350 NMi. It will also be noted that spacecraft with projected areas $\gtrsim$ 30 m^2 have a good probability of being hit during a 10-year mission.

SPACE DEBRIS OBJECT ENVIRONMENT FOR LEO ORBITS

[28° INCLINATION; CIRCULAR EARTH ORBITS]



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MATERIAL THICKNESS TO STOP OBJECTS IN SPACE

While cometary meteoroids have low average densities ($\sim$0.5 gm/cm^3) and high average velocities ($\sim$20 km/sec relative to spacecraft in posigrade earth orbits) space debris objects have higher average densities ($\sim$2.8 gm/cm^3) but lower average velocities ($\sim$9 km/sec). The thickness of a single sheet of aluminum or stainless steel to stop a particle of a given mass is approximately the same for objects of either type. The thickness of a single sheet of either aluminum or stainless steel to stop these objects is shown here as a function of object mass. It will be noted that a single sheet of aluminum 1 gm/cm^2 = 0.37 cm thick will be penetrated by objects of mass $\gtrsim 2.5 \times 10^{-4}$ gm. By using two sheets of aluminum (0.06 cm thick and 0.31 cm thick) separated by at least 9 cm, the mass per unit area will still be 1 gm/cm^2 but this double walled configuration will be as effective as a single sheet of aluminum 1.85 cm thick in stopping meteoroids (and be able to stop objects $\lesssim 2.5 \times 10^{-2}$ gms).

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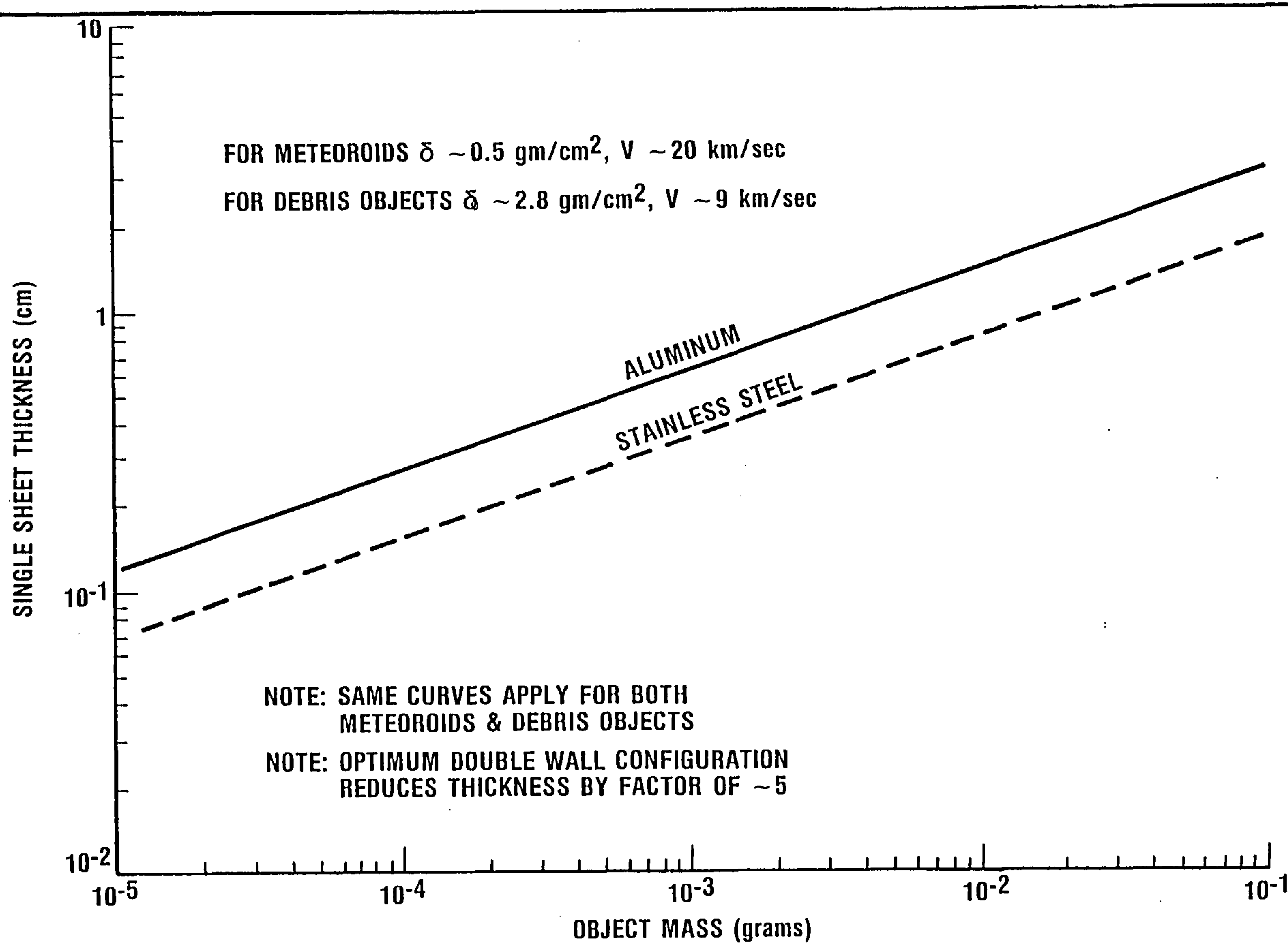
MATERIAL THICKNESS TO STOP OBJECTS IN SPACE



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Based upon the thicknesses of various parts of the Spacecraft 90 configurations and the solid angles they subtend at the electronics boxes, the effective shielding varies from $\sim$1 gm/cm^2 (at the exposed corners of the boxes) to $\sim$15 gm/cm^2 (at the centers of boxes). Carefully chosen semiconductor electronic devices and well designed electronic circuits can tolerate a total nuclear radiation dose of $\sim 10^5$ rads. Based upon 1 gm/cm^2 of effective shielding and a 10 year mission dose it has been shown that these 10^5 rad electronics will be just adequate for the geosynchronous earth orbit (GEO), more than adequate for low earth orbits (LEO) up to 600 NMi altitude, but inadequate for the Global Positioning Spacecraft (GPS) orbit (all for the natural Van Allen belts). If bomb-produced trapped fission electrons are present, they will limit mission lifetimes to less than 1 year unless additional shielding is provided. In addition, the debris object flux makes LEO altitudes $\lesssim$ 400 NMi peferrable.

SUMMARY - CONCLUSIONS

- EQUIVALENT SPACECRAFT ELECTRONICS SHIELDING
  - ~1 GM/CM^2 MINIMUM (EXPOSED CORNER OF ELECTRONICS BOX)
  - ~15 GM/CM^2 MAXIMUM (CENTER OF ELECTRONICS BOX)
- ELECTRONICS CAN TOLERATE ~ 10^5 RADS TOTAL DOSE
  - SOME COMPONENTS $< 10^5$ RADS, OTHERS $> 10^5$ RADS
- FOR GEO ORBIT, 10^5 RADS ⇨ 10 YEAR LIFETIME (NATURAL)
- FOR GPS ORBIT, 10^5 RADS ⇨ 1 YEAR LIFETIME (NATURAL)
  - NEED 2.3 GM/CM^2 FOR 10 YEARS IN GPS ORBIT
- FOR 600 NMi ORBIT, 10^5 RADS ⇨ 50 YEAR LIFETIME (NATURAL)
  - DEBRIS LIMITS ALTITUDE TO $\leqslant$ 400 NMi FOR 10 YEARS
- FOR TRAPPED FISSION ENVIRONMENT, < 1 YEAR AT ALL ALTITUDES

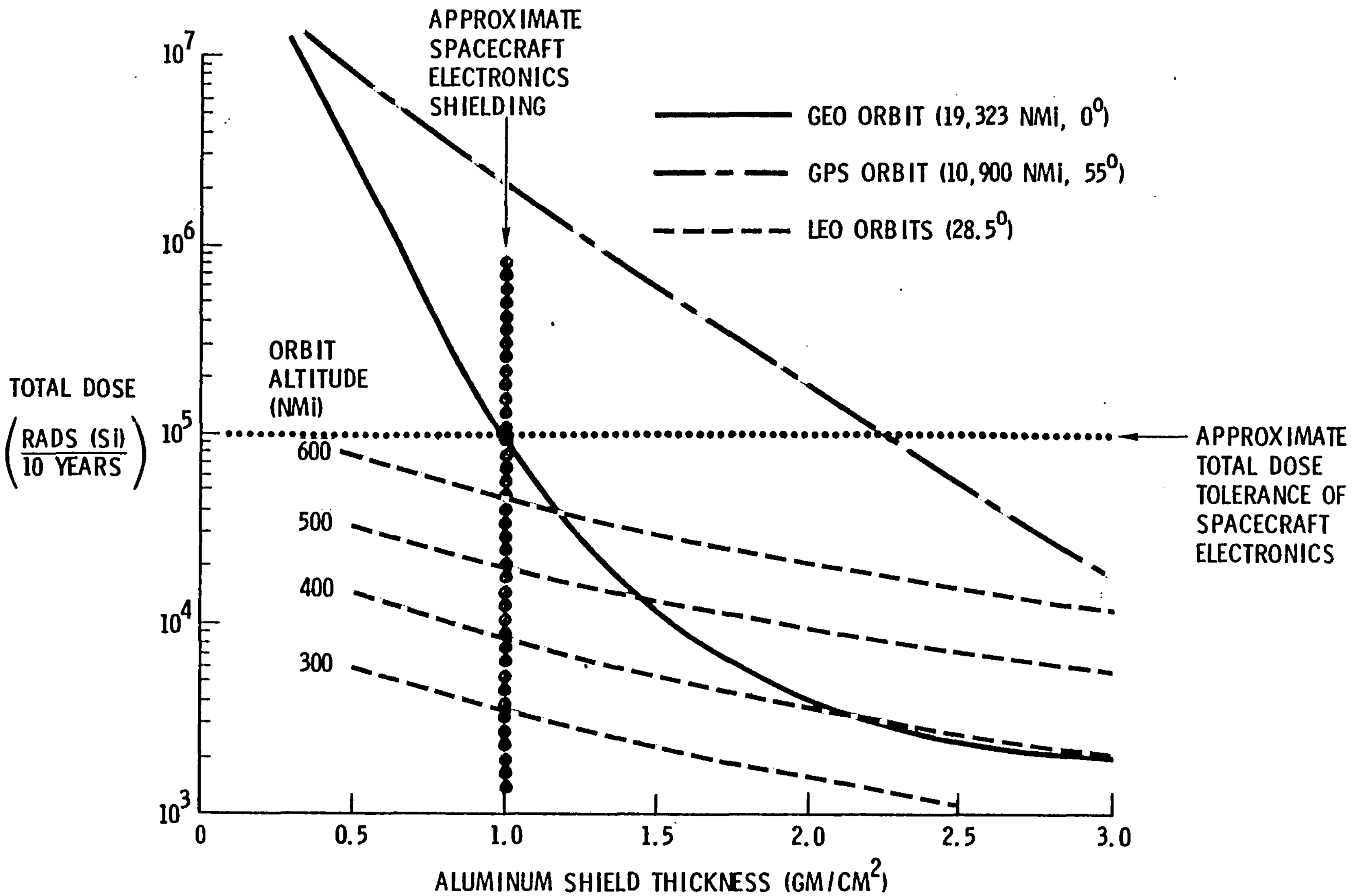
$$\text{NEED} \left.\begin{array}{l} \geqslant 2.8\ GM/CM^2\ \text{(a) 400 NMi} \\ \geqslant 2.5\ GM/CM^2\ \text{(a) GPS} \\ \geqslant 1.3\ GM/CM^2\ \text{(a) GEO} \end{array}\right\} \begin{array}{l}\text{FOR 10 YEAR LIFE} \\ \text{IF TRAPPED FISSION } \bar{e}\end{array}$$

NUCLEAR RADIATION ENVIRONMENTS FOR S/C-90 ORBITS

The chart opposite summarizes the preceding discussion on spacecraft radiation survivability for the condition of 1-JSC or natural environment radiation levels.

10 year spacecraft electronics survival is achieved through the current routine use of aluminum, at 1 gram/cm^2, for spacecraft at LEO and GEO orbits. Significantly higher levels of aluminum shielding are required for GPS type orbits at 10,900 NMi, 55°.

NUCLEAR RADIATION ENVIRONMENTS FOR SPACECRAFT 90 ORBITS

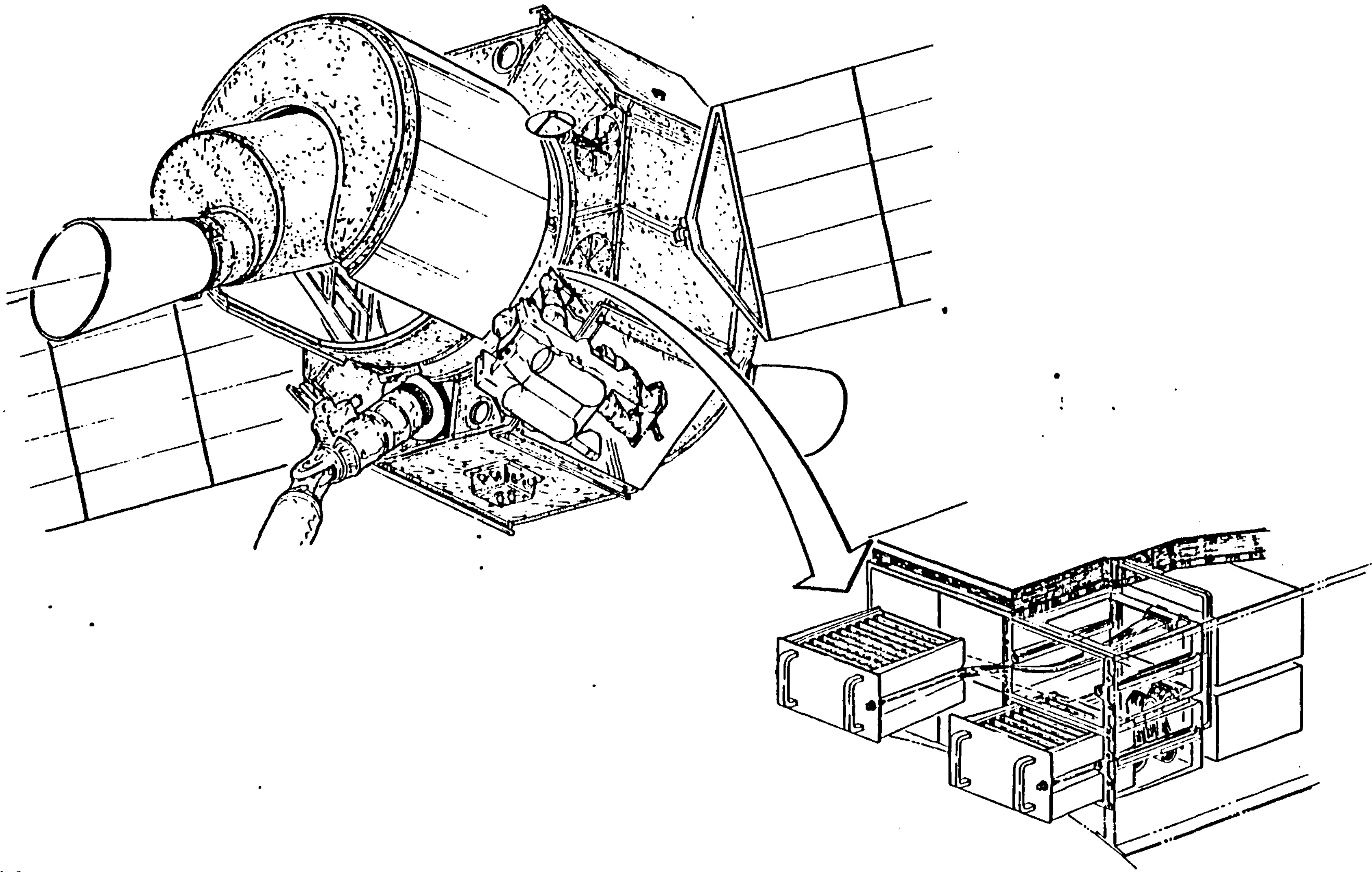


The penalty that must be paid to survive in a higher radiation environment is illustrated opposite. The "open" structural concept is no longer feasible, so that the ease for accessibility characteristic must be sacrificed in order to put all spacecraft vulnerable components inside a protective structure.

The other major features of the high-technology spacecraft can be retained however - such as the concept for electronic packaging; the integration of thermal, structural, and electronic packaging; integration of the high speed data bus and distributed data processing.

ADVANCED SPACECRAFT

SURVIVABLE CONCEPT



APPENDIX - C

EVALUATION/SELECTION CRITERIA

APPENDIX - C

EVALUATION/SELECTION CRITERIA

The material in this Appendix C was developed in the course of the study contract, and presents to varying degrees of detail and format, the logic and rationale for selecting a specific design or technology concept from among the alternatives available.

No attempt was made to treat each subsystem/technology to precisely the same format. However, the material is presented here, much as initially prepared by the individual technologist, to assist the reader in understanding the selection rationale for the total advanced technology spacecraft system.

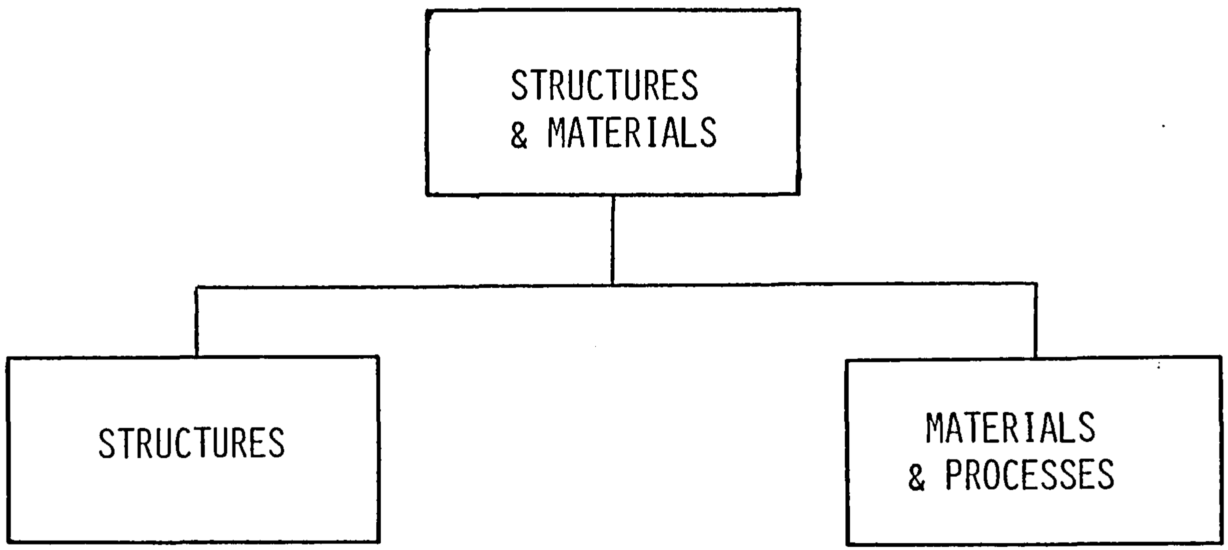
The technology areas included here are:

- Structures & Materials
- Thermal Management
- Propulsion
- Electrical Power
- Guidance, Navigation & Control
- Data Management

Each technology section will contain:

- A Subsystem Block Diagram
- An evaluation matrix in one form or another
- A Subsystem Trade Tree

- SUBSYSTEM: STRUCTURE/MATERIALS



ALTERNATIVES EVALUATION (1)

CONFIGURATION IS GOVERNED BY:

- LAUNCH VEHICLE REQ'TS
- PAYLOAD REQ'TS
- OPERATIONS REQ'TS
- MAINTENANCE REQ'TS
- LOADS & ENVIRONMENT
- MISSION ADAPTABILITY

ALTERNATIVE STRUCTURE CONFIGURATIONS

- HONEYCOMB CONSTRUCTION
  - \+ LOW WEIGHT
  - \+ HIGH RELATIVE STIFFNESS
  - \+ GOOD DAMPING CHARACTERISTICS
  - \+ LOW COST
  - \+ GOOD PRODUCIBILITY
  - \+ HIGH STRENGTH
- SEMI-MONOCOQUE
  - \- MEDIUM TO HIGH RELATIVE WEIGHT
  - \- LOW RELATIVE STIFFNESS
  - \- POOR DAMPING CHARACTERISTICS
  - \+ LOW-COST FABRICATION
  - \+ GOOD PRODUCIBILITY
  - \+ RELATIVELY GOOD STRENGTH
- HY-BRID
  - \+ LOW RELATIVE WEIGHT
  - o STIFFNESS CONFIGURATION DEPENDENT
  - o DAMPING CONFIGURATION DEPENDENT
  - \- RELATIVE HIGH COST
  - \+ GOOD PRODUCIBILITY
  - \+ HIGH STRENGTH
- MONOCOQUE
  - \+ LOW WEIGHT
  - \- LOW RELATIVE STIFFNESS
  - \- POOR DAMPING CHARACTERISTICS
  - \+ LOW FABRICATION COST
  - \+ GOOD PRODUCIBILITY
  - \+ RELATIVELY GOOD STRENGTH

ALTERNATIVES EVALUATION (2)

- ALUMINUM
  - \- LOW STRENGTH/DENSITY
  - \- LOW STIFFNESS/DENSITY
  - \+ GOOD CONDUCTIVITY/DENSITY
  - \+ NO OUT-GASSING
  - \+ NO VACUUM CONDENSABLE MATERIAL
  - \+ ULTRA-VIOLET STABLE
  - \+ LOW COST
  - \+ GOOD PRODUCIBILITY
- TITANIUM
  - \+ HIGH STRENGTH/DENSITY
  - \- LOW STIFFNESS/DENSITY
  - \- POOR CONDUCTIVITY/DENSITY
  - \+ NO OUT-GASSING
  - \+ NO VACUUM CONDENSABLE MAT'L
  - \+ ULTRA-VIOLET STABLE
  - \+ MEDIUM COST
  - \- POOR PRODUCIBILITY
- COMPOSITE
  - \+ HIGH STRENGTH/DENSITY
  - \+ HIGH STIFFNESS/DENSITY
  - \+ GOOD CONDUCTIVITY/DENSITY
  - \- POOR OUT-GASSING CHARACTERISTICS
  - \- MAY CONTAIN VACUUM CONDENSABLE MAT'L
  - \+ ULTRA-VIOLET STABLE
  - o INDETERMINATE COST/COMPOUND DEPENDENT
  - \+ GOOD PRODUCIBILITY
- BERYLLIUM
  - \- LOW STRENGTH/DENSITY
  - \+ HIGH STIFFNESS/DENSITY
  - \+ GOOD CONDUCTIVITY/DENSITY
  - \+ NO OUT-GASSING
  - \+ NO VACUUM CONDENSABLE MAT'L
  - \+ ULTRA-VIOLET STABLE
  - \+ MEDIUM COST
  - \- POOR PRODUCIBILITY

EVALUATION

SUBSYSTEM : STRUCTURE / MATERIALS

STRUCTURE

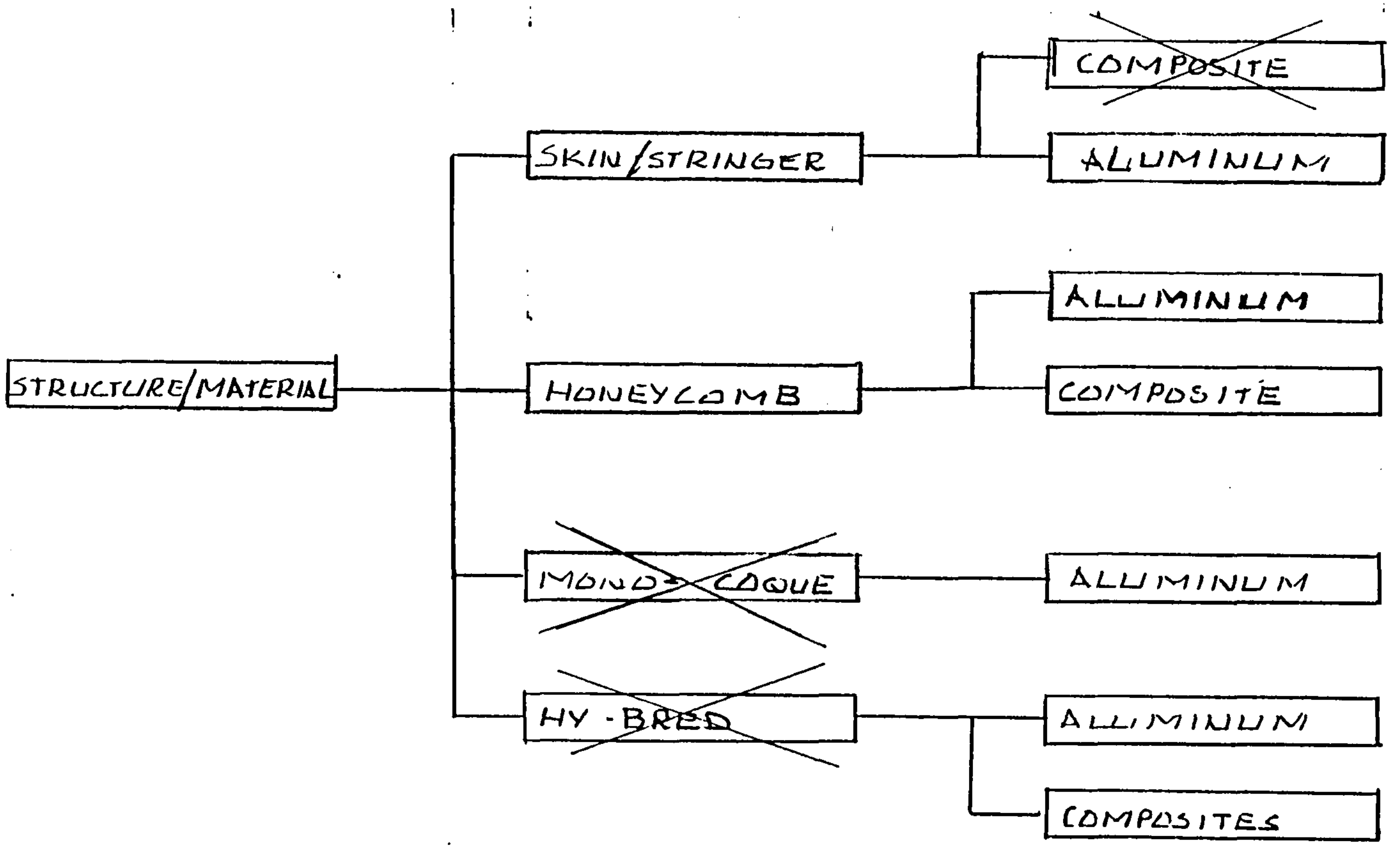
PERFORMANCE CRITERIA	ALTERNATIVES: SKIN/STGR	MONO-COQ	HONEY COMB	HY-BRED
WEIGHT	−	?	+	+
STIFFNESS	+	−	+	+
DAMPING	−	?	+	+
COST	+	?	+	?
PRODUCIBILITY	+	?	+	?
STRENGTH	+	+	+	+

MATERIALS

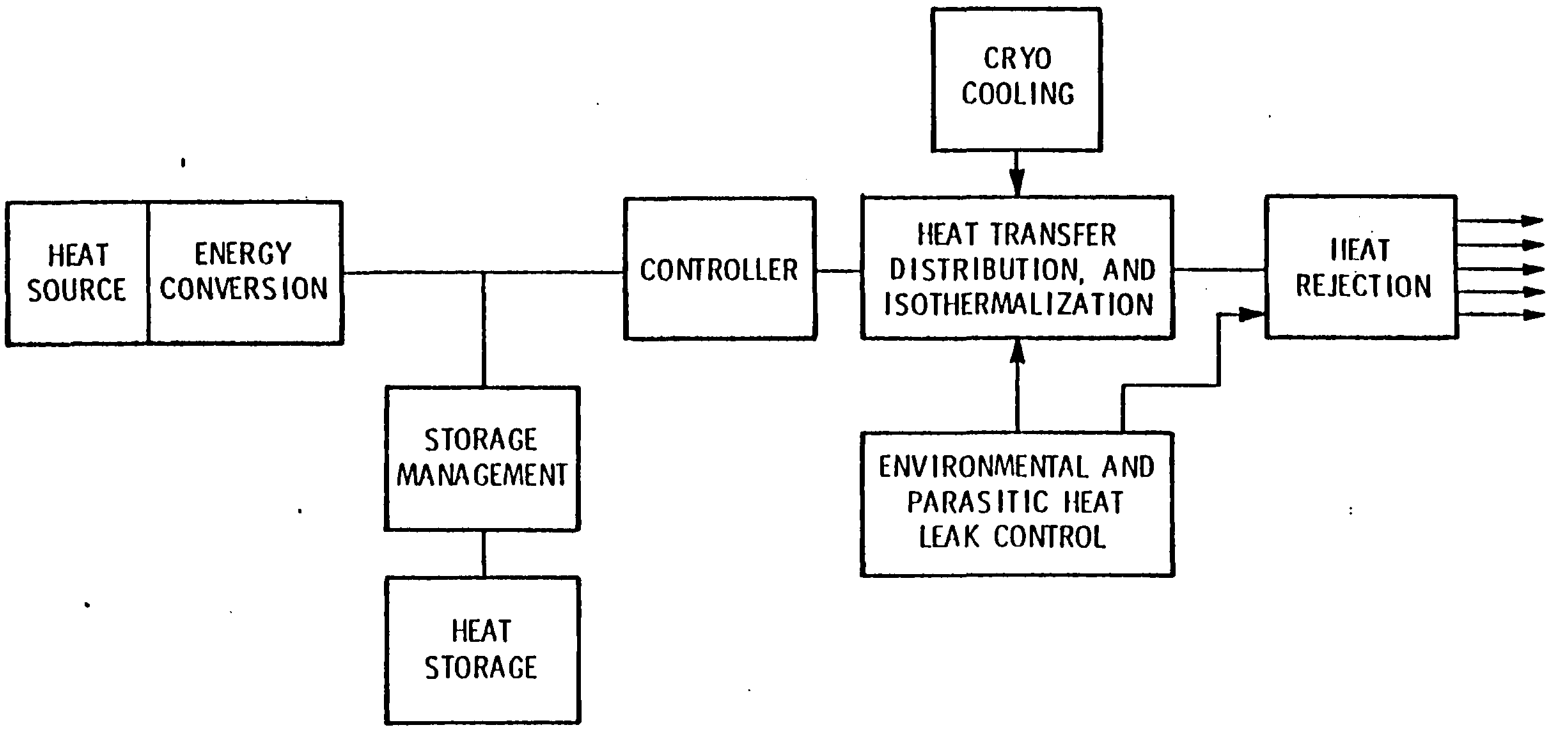
PERFORMANCE CRITERIA	MATERIAL ALTERNATIVES					PAINT ALTERNATIVES		
	ALUM	TIT.	COMP	BER.	METAL MATRIX	SILI-CONE	EPOXY	URE-THANE
S. STRENGTH	−	+	+	−	+			
S. STIFFNESS	−	−	+	+	+			
S. CONDUCT.	+	−	+	+	+			
LOW OUT-GAS	+	+	−	+	+	−	−	+
VAC CON MAT	+	+	−	+	+	+	+	+
UV STABLE	+	+	+	+	+	−	+	−
COST	+	+	0	+	−			
PRODUCIBILITY	+	−	+	−	−			

TRADE TREE

- SUBSYSTEM : STRUCTURE / MATERIALS



TCS SIMPLIFIED BLOCK DIAGRAM



TCS OPTIONS

HEAT TRANSPORT AND DISTRIBUTION	HEAT REJECTION RADIATOR	HEAT COLLECTION DEVICES	TEMPERATURE CONTROLLERS
COLD BIAS SPACECRAFT		• DOUBLERS • DIRECT MOUNT	• HEATERS AND • CONTROLLER OR THERMOSTAT
LOUVER CONTROL SPACECRAFT	• LOUVERS AND BI-METALLIC CONTROLS	• DOUBLERS • DIRECT MOUNT	• HEATERS AND • CONTROLLER OR THERMOSTAT
HEAT PIPE CONTROL SPACECRAFT	• HEAT PIPES • VCHP • DIODE HEAT PIPES	• HEAT PIPES	• HEATERS AND • CONTROLLER OR THERMOSTAT
CAPILLARY PUMP LOOP (CPL)	• CONDENSER/HEAT PIPES • DIRECT CONDENSING	• EVAPORATIVE COLD PLATES	• FLOW CONTROL VALVES AT SPACECRAFT COMPONENTS • PRESSURE CONTROL AT CENTRAL RESERVOIR
PUMPED FLUID LOOP	• REDUNDANT FLUID LOOPS • HEAT EXCHANGER/HEAT PIPES	• CONVECTIVE COLD PLATE • HEAT EXCHANGE COILS	• VARIABLE FLOW AT FIXED TEMPERATURE • FIXED FLOW WITH VARIABLE HEAT
2-PHASE PUMP FLUID LOOP	• CONDENSER/HEAT PIPES • DIRECT CONDENSING	• EVAPORATIVE COLD PLATES	• VARIABLE FLOW WITH FIXED TEMPERATURE • FIXED FLOW WITH VARIABLE HEAT
2-PHASE COMPRESSED VAPOR LOOP	• CONDENSER/HEAT PIPES • DIRECT CONDENSING	• EVAPORATIVE COLD PLATES	• VARIABLE FLOW WITH FIXED TEMPERATURE • FIXED FLOW WITH VARIABLE HEAT

TCS EVALUATION
HEAT TRANSPORT AND DISTRIBUTION

	LOW RISK	DISTRIBUTION WEIGHT PENALTY	POWER WEIGHT PENALTY	CONTROL SYSTEM COMPLEXITY	SPACECRAFT VOLUME UTILIZATION	DESIGN CHANGE COST	CONFIGURATION CONSTRAINTS	TRANSPORT LIMITS	SURVIVABILITY	SUMMATION
COLD BIAS SPACECRAFT	+	-	-	-	-	-	0	-	-	1
LOUVER CONTROL SPACECRAFT	+	-	0	0	-	-	0	-	-	1
HEAT PIPE CONTROL	0	0	+	-	+	+	-	-	+	4
CAPILLARY PUMPED FLUID	-	-	+	+	+	+	+	+	+	7
SINGLE-PHASE PUMPED FLUID	+	0	-	-	+	+	+	+	-	5
TWO-PHASE PUMPED FLUID	-	0	+	-	+	0	-	+	+	4
TWO-PHASE COMPRESSION	+	-	-	-	+	+	0	+	-	4

TCS EVALUATION

	LOW RISK	DISTRIBUTION WEIGHT PENALTY	POWER WEIGHT PENALTY	CONTROL SYSTEM COMPLEXITY	SPACECRAFT VOLUME UTILIZATION	DESIGN CHANGE COST	CONFIGURATION CONSTRAINTS	TRANSPORT LIMITS	SURVIVABILITY	SUMMATION
HEAT REJECTION RADIATORS										
LIQUID LOOP	+	0	-	-	0	0	+	+	0	3
HEAT PIPE	0	0	+	+	0	-	+	-	+	4
CPL CONDENSER	-	-	+	+	0	+	+	+	+	6
HEAT COLLECTION DEVICES										
COLD PLATES - CONVECTIVE	-	-	-	-	-	-	+	+	+	3
COLD PLATES - EVAPORATIVE	0	-	+	+	-	-	+	+	+	5
COLD PLATES - COMPONENT MOUNTING STRUCTURE	0	-	0	0	+	-	0	+	+	3
HEAT EXCHANGERS - COILS	0	-	0	0	+	-	+	+	+	4

TCS EVALUATION

	LOW RISK	DISTRIBUTION WEIGHT PENALTY	POWER WEIGHT PENALTY	CONTROL SYSTEM COMPLEXITY	SPACECRAFT VOLUME UTILIZATION	DESIGN CHANGE COST	CONFIGURATION CONSTRAINTS	TRANSPORT LIMITS	SURVIVABILITY	SUMMATION
CONTROLLER										
VARIABLE FLOW, FIXED TEMPERATURE	0	-	-	-	0	0	+	+	+	3
FIXED FLOW, VARIABLE HEAT	0	-	-	-	0	0	+	+	+	3
CPL EVAPORATOR	+	-	+	+	0	0	+	+	+	6
HEAT STORAGE										
RADIATOR MOUNT CAPACITOR	-	-	0	0	+	-	-	-	-	1
COMPONENT MOUNT CAPACITOR	+	-	0	0	+	-	-	-	+	3
IN-LINE FLOW CAPACITOR	0	-	0	-	+	+	+	-	+	4
ENVIRONMENT CONTROL										
MODULAR MLI BLANKETS	+	+	+	+	+	-	-	+	0	6

CRITERIA	COLD BIAS SPACECRAFT	LOUVER CONTROL	HEAT PIPE CONTROL	CAPILLARY PUMPED FLUID LOOP	SINGLE-PHASE FLUID LOOP	TWO-PHASE PUMPED FLUID LOOP	COMPRESSION CYCLE	REMARKS
RISK	+	+	0	−	+	−	+	
DISTRIB. WEIGHT PENALTY	−	−	0	−	0	0	−	
POWER WEIGHT PENALTY	−	0	+	+	−	+	−	
CONTROL SYSTEM COMPLEXITY	−	0	+	+	−	−	−	
S/C VOLUME UTILIZATION	−	−	+	+	+	+	+	
DESIGN CHANGE COST	−	−	+	+	+	0	+	
CONFIGURATION CONSTRAINTS	0	0	−	+	+	−	0	
TRANSPORT LIMITS	−	−	−	+	+	+	+	
SURVIVABILITY	−	−	+	+	−	+	−	
NO OF PLUSES	1	1	4	7	5	4	4	

—RANKING OF THERMAL CONTROL SYSTEM OPTIONS

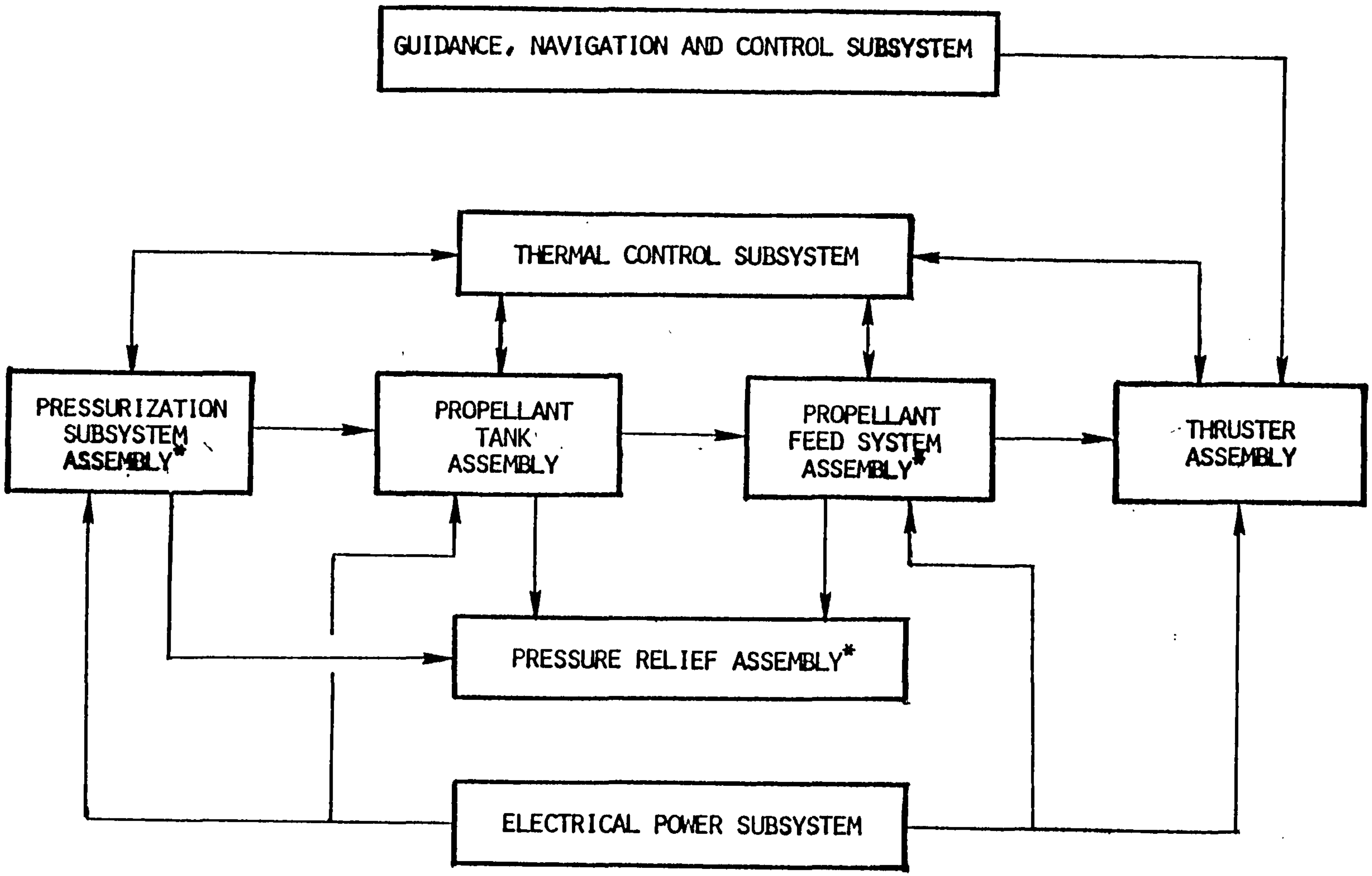
ACTIVE	PASSIVE	SYSTEMS
	1	CAPILLARY PUMPED LOOP SYSTEM
2		SINGLE-PHASE FLUID LOOP
	3	HEAT PIPE SYSTEM
4		COMPRESSION CYCLE
5		LOUVER CONTROL SYSTEM
	6	COLD BIAS SPACECRAFT
7		TWO-PHASE PUMPED LOOP

TRADE TREE

HEAT TRANSPORT	HEAT REJECTION	HEAT COLLECTION	TEMPERATURE CONTROL	HEAT STORAGE
COLD BIAS SPACECRAFT	SIMPLE	DIRECT MOUNT	COLD BIAS HEATERS	COMPONENT MOUNT
LOUVER CONTROL	LOUVER	HEAT PIPES	VARIABLE FLOW FIXED TEMP	RADIATOR MOUNT
HEAT PIPE CONTROL	HEAT PIPE	CONVECTIVE COLD PLATE	FIXED FLOW VARIABLE HEAT	✓ IN-LINE FLOW
✓ CAPILLARY PUMP LOOP	FLUID LOOP	✓ EVAPORATIVE COLD PLATE	✓ CAP PUMP LOOP VARIABLE HEAT	
PUMPED FLUID LOOP	CONDENSING	HEAT EXCHANGERS		
TWO-PHASE PUMPED LOOP	✓ CONDENSING HEAT PIPE			
TWO-PHASE COMPRESSION	FLUID LOOP HEAT PIPE			

✓ - SELECTED

PROPULSION SUBSYSTEM SIMPLIFIED BLOCK DIAGRAM



*LIQUID OR GAS SYSTEM ONLY

PROPULSION SUBSYSTEM
THRUSTER ALTERNATIVES EVALUATION

GENERAL REQUIREMENTS	SERVICE LIFE SERVICING REDUNDANCY COST	TOTAL IMPULSE SAFETY EASY ACCESS MODULAR	AUTONOMY SPINNING/3-AXIS STABILIZED MANEUVERING
ADDITIONAL SELECTION CRITERIA	RESTART ENGINE ALIGNMENT PROPELLANTS SELECTED	THROTTLING PLUME IMPINGEMENT CONTAMINATION	MAX G LEVELS

ASSEMBLY EVALUATION

+ SOLID ROCKET MOTOR - SINGLE BURN. EXHAUST PLUME CONTAINS CONTAMINATES.
+ LIQUID CHEMICAL ENGINES - RESTARTABLE. BIPROPELLANT OR MONOPROPELLANT. SELECTIONS AVAILABLE:
  - CRYOGENIC BIPROP - HIGH I_{SP} & THRUST. SHORT SERVICE LIFE.
  - SPACE-STORABLE BIPROP - MEDIUM I_{SP}, SMALL TO MEDIUM THRUST, LONG SERVICE LIFE.
  - SPACE-STORABLE MONOPROP - LOW TO MEDIUM I_{SP}, LOW TO MEDIUM THRUST, LONG SERVICE LIFE.
- INERT GAS THRUSTER - VERY LOW I_{SP}, VERY LOW TO MEDIUM THRUST, LONG SERVICE LIFE.
- PULSED ELECTRIC THRUSTERS - ULTRA HIGH I_{SP}, VERY LOW THRUST, LONG SERVICE LIFE, HIGH POWER REQUIREMENTS.
- MAGNETO PLASMADYNAMIC THRUSTERS - ULTRA HIGH I_{SP}, LOW THRUST, HIGH POWER REQUIREMENTS, SERVICE LIFE UNKNOWN.
- SOLAR THRUSTERS - ULTRA HIGH I_{SP}, NO PROTOTYPE.
- NUCLEAR & LASER THRUSTERS - ULTRA HIGH I_{SP}, MEDIUM TO HIGH THRUST, HIGH POWER REQUIREMENTS, SERVICE LIFE UNKNOWN, POTENTIALLY UNSTABLE.

PROPULSION SUBSYSTEM
PRESSURIZATION ALTERNATIVES EVALUATION

GENERAL REQUIREMENTS:	SERVICE LIFE SERVICING REDUNDANCY COST	EASY ACCESS MODULAR SAFETY SPINNING/3-AXIS STABILIZED
ADDITIONAL SELECTION CRITERIA	PROPELLANT COMPATIBILITY	AVAILABLE GAS SOURCE

ASSEMBLY EVALUATION

+ BLOWDOWN - SIMPLEST CONCEPT. PRESSURE VARIATION CAUSES THRUST VARIATION. GAS TANK MAY BE REQUIRED.
+ PRESSURE-REGULATED - CONSTANT ULLAGE PRESSURE. COMPLEX SYSTEM OF HARDWARE.
- SELF-PRESSURIZED - HIGH PROPELLANT VAPOR PRESSURE REQUIRED. NO GAS TANKS. ZERO NPSH SYSTEM.
+ AUTOGENOUS - SUPERHEATED PROPELLANT VAPOR. FOR USE DURING THRUSTER OPERATION ONLY. MAY NEED A PRE-PRESSURIZATION SYSTEM.
- PISTONS/BELLOWS - FORCED EXPULSION WITH PROPELLANT MANAGEMENT DEVICE. CYCLE LIMITED.
- COMBUSTION PRODUCTS - HOT GAS SYSTEM FROM AN EXTERIOR GAS SOURCE.

PROPULSION SUBSYSTEM

PROPELLANT TANK ALTERNATIVES EVALUATION

GENERAL REQUIREMENTS	SERVICE LIFE	EASY ACCESS
	SERVICING/RETRIEVAL	MODULAR
	REDUNDANCY	AUTONOMY
	COST	SPINNING/3-AXIS STABILIZED
	TOTAL IMPULSE VELOCITY	MANEUVERING
	PAYLOAD SIZE/WEIGHT	SAFETY
ADDITIONAL SELECTION CRITERIA	OPERATING PRESSURE/TEMPERATURE	MATERIAL COMPATIBILITY
	PROPELLANTS SELECTED	PACKAGING CONSTRAINTS

ASSEMBLY EVALUATION

MATERIAL

+ LIQUID PROPELLANT - ALUMINUM, TITANIUM, STAINLESS STEEL, FILAMENT-WRAPPED METAL TANK
+ SOLID PROPELLANT - COMPOSITES, FIBERGLASS, FILAMENT CASING

TANK SHAPE

+ SPHERICAL
+ ELLIPSOIDAL
+ COMMON BULKHEAD
+ TORUS
- REGULAR POLYGON

PROPELLANT MANAGEMENT DEVICE

+ VANE
+ ELASTOMERIC DIAPHRAGM
+ SCREENS

PROPULSION SUBSYSTEM

PROPELLANT FEED SYSTEM ALTERNATIVES EVALUATION

GENERAL REQUIREMENTS	SERVICE LIFE SERVICING REDUNDANCY	COST MODULAR EASY ACCESS SAFETY
ADDITIONAL SELECTION CRITERIA	PROPELLANT USED DISASSEMBLY REQUIREMENTS	OPERATING PRESSURE/TEMPERATURE PERMISSIBLE PRESSURE DROP

ASSEMBLY EVALUATION

+ MATERIAL - PROPELLANT COMPATIBILITY DETERMINES SELECTION
+ VALVES - USAGE & COST ARE SELECTION DRIVERS

MANUAL VALVES	PNEUMATIC VALVES
ELECTRICAL VALVES	PYROTECTIC VALVES

+ THERMAL CONTROL
  - SPACE-STORABLE PROPELLANTS - INSULATION, ACTIVE HEATING SYSTEM
  - CRYOGENIC PROPELLANTS - INSULATED/VACUUM-JACKETED SYSTEMS

PROPULSION SUBSYSTEM

PRESSURE RELIEF ALTERNATIVES EVALUATION

GENERAL REQUIREMENTS	SERVICE LIFE SERVICING REDUNDANCY COST CONTAMINATION	EASY ACCESS MODULAR SAFETY AUTONOMY
ADDITIONAL SELECTION CRITERIA	PERMISSIBLE LEAKAGE NON-PROPULSIVE VENTING EXHAUST GAS IMPINGEMENT	

ASSEMBLY EVALUATION

+ BURST DISC - SINGLE USAGE UNIT. ZERO LEAKAGE UNIT.
+ RELIEF VALVE - REUSABLE UNIT. VERY LOW LEAKAGE UNIT.
+ BURST DISC/RELIEF VALVE COMBINATION - DESIGN CONCEPT WHICH DOES NOT ALLOW LEAKAGE UNTIL AFTER INITIAL USE.
- EXPANDING VOLUME - ELASTOMER OR BELLOWS CONCEPT WHICH PERMITS A CHANGE OF VOLUME TO MAINTAIN CONSTANT PRESSURE.

SYSTEM ASSEMBLY SELECTION

ADVANCED GPS

OTV

- 1990 LAUNCH FROM SHUTTLE
- IMPULSE VELOCITY REQ'D = 13,314 FT/SEC
- PAYLOAD WEIGHT = 2,200 LBM
- 3-AXIS STABILIZED

RANKING	CANDIDATES	SOA RATING
1	LOX/LH_2 CENTAUR G	3
2	SRM IUS	3
3	TOS/AMS	2
4	MODIFIED PAM D-II	2

RCS

- TEN YEAR SERVICE LIFE
- 10,900 N.MI CIRCULAR ORBIT
- T/W MAX - 0.04
- IMPULSE VELOCITY REQ'D = 328 FT/SEC
- MAXIMUM TORQUES = TBD
- 3-AXIS STABILIZED

RANKING	CANDIDATES	SOA RATING
1	PRESSURE-FED N_2H_4, GN_2 BLOWDOWN	3
2	PRESSURE-FED N_2H_4, GH_E BLOWDOWN	3
3	PRESSURE-FED N_2H_4, PRESSURE-REGULATED	3
4	PRESSURE-FED SPACE STORABLE BIPROPELLANT, PRESSURE-REGULATED	3

SYSTEM ASSEMBLY SELECTION
SPACE MANUFACTURING/PROCESSING SATELLITE

OTV

- 1991 LAUNCH FROM SHUTTLE (INITIAL)
- IMPULSE VELOCITY REQUIRED = 2,232 FT/SEC
- PAYLOAD WEIGHT = 25,000 LBM
- 3-AXIS STABILIZED
- SERVICEABLE OTV
- TEN SHUTTLE LAUNCHES
- RETRIEVE EVERY 6 MONTHS

RANKING	CANDIDATES	SOA RATING
1	SPACE-STORABLE, BIPROPELLANT PRESSURE-FED, PRESSURE-REG. SYS.	3
2	SPACE-STORABLE , MONOPROPELLANT PRESSURE-FED, BLOWDOWN SYS.	3
3	SPACE-STORABLE, BIPROPELLANT PUMP-FED, BLOWDOWN	2

NOTE: THE ORBITAL SCIENCE CORPORATION'S APOGEE MANEUVER STAGE (AMS) MEETS THE REQ'TS FOR SELECTION NO. 1.

RCS

- FIVE YEAR SERVICE LIFE
- 500 N.M. CIRCULAR ORBIT @ 28.5° INC.
- T/W MAX = TBD
- EXPENDABLES FOR 7 MOS.
- IMPULSE VELOCITY = 100 FT/SEC PER MISSION
- MAXIMUM TORQUES = TBD
- 3-AXIS STABILIZED
- RESERVICEABLE

RANKING	CANDIDATES	SOA RATING
1	INERT GAS, PRESSURE-FED PRESSURE-REGULATED SYSTEM	3
2	SPACE-STORABLE, MONOPROPELLANT PRESSURE-FED, BLOWDOWN SYS.	3
3	SPACE-STORABLE, PRESSURE-FED PRESSURE-REGULATED BIPROP. SYSTEM	3

USE SELECTION NO. 3, SINCE THE RCS COMES INTEGRATED WITH THE OSC AMS.

SYSTEM ASSEMBLY SELECTION

COMMERCIAL COMSAT

OTV

- 1991 LAUNCH FROM SHUTTLE
- IMPULSE VELOCITY REQ'D = 13,886 FT/SEC
- PAYLOAD WT = 11,000 LBM
- 3-AXIS STABILIZED

RANKING	CANDIDATES	SOA RATING
1	CENTAUR G'	3

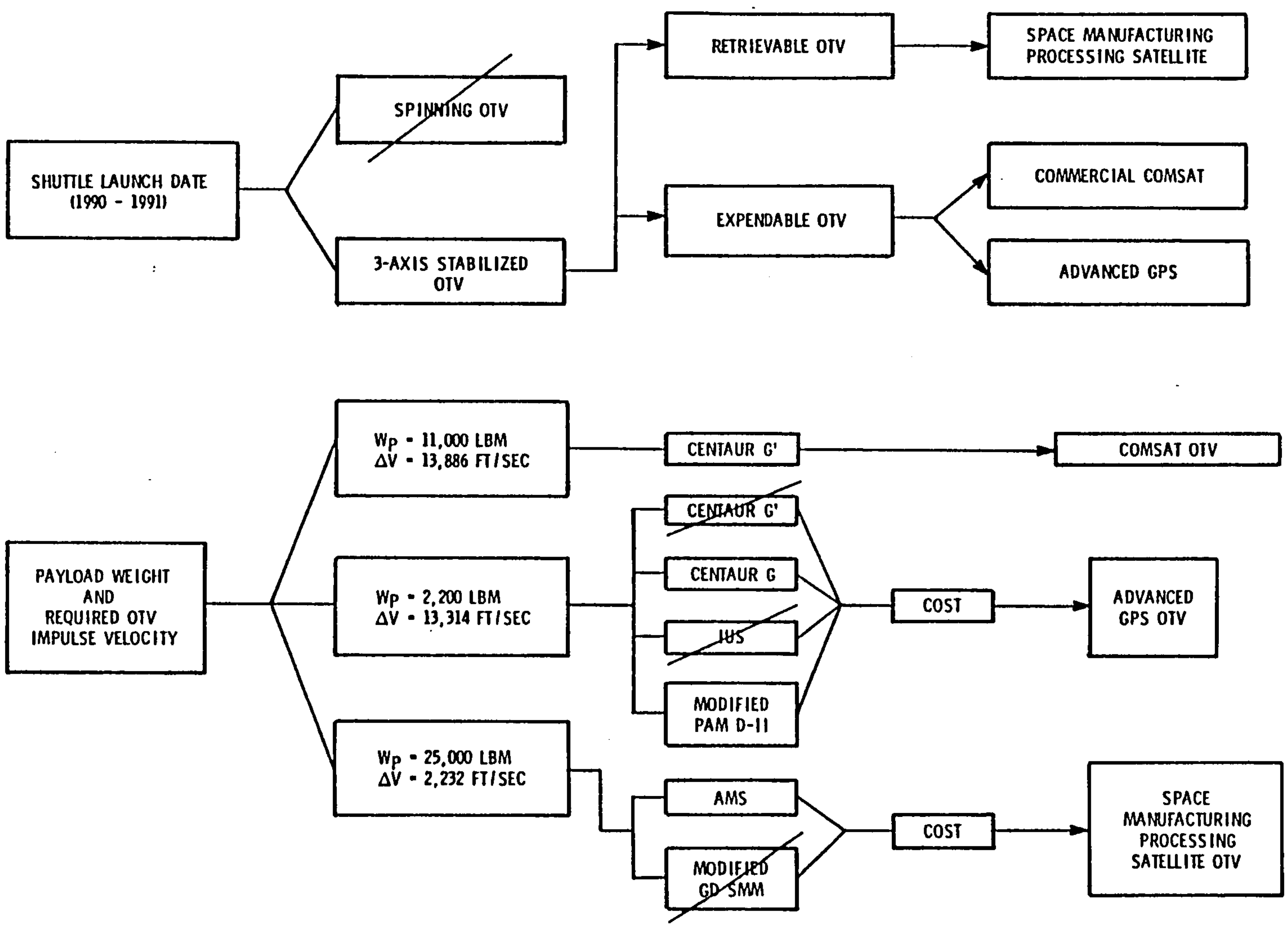
ONLY KNOWN OTV THAT CAN LIFT PAYLOAD AND ANTICIPATED RCS WEIGHT INTO ORBIT

RCS

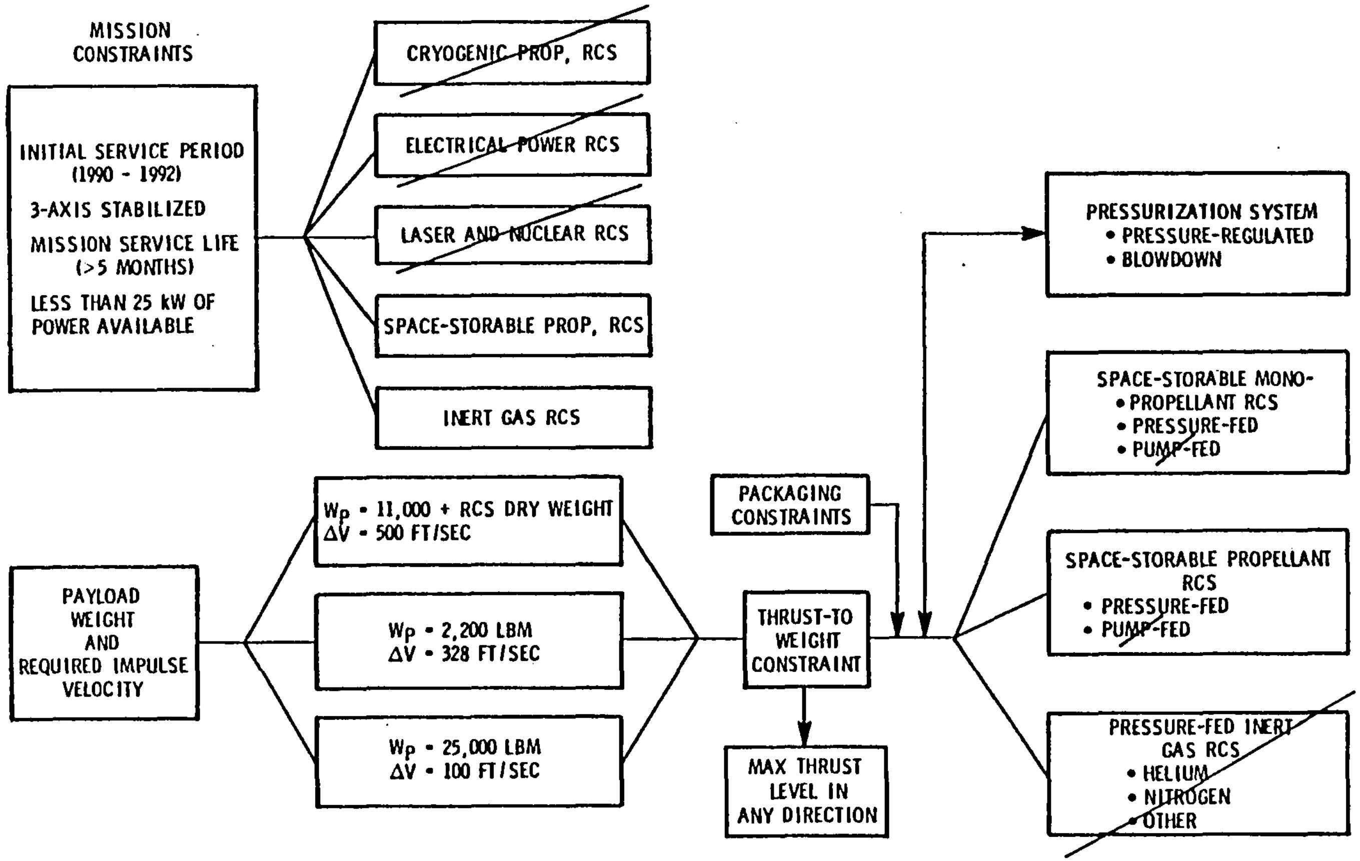
- TEN YEAR SERVICE LIFE
- GEOSYNCHRONOUS ORBIT
- T/W MAX = 0.01
- IMPULSE VELOCITY = 500 FT/SEC
- MAXIMUM TORQUES = TBD
- 3-AXIS STABILIZED

RANKING	CANDIDATES	SOA RATING
	SPACE-STORABLE PROPELLANT PROPULSION SYSTEM	
1	PRESSURE-FED, PRESSURE REG.	3
2	PRESSURE-FED, BLOWDOWN	3
3	PUMP-FED, PRESSURE-REGULATED	2
4	PUMP-FED, BLOWDOWN	2
	INERT GAS PROPULSION SYSTEM	
5	PRESSURE-FED, PRESSURE REG.	3

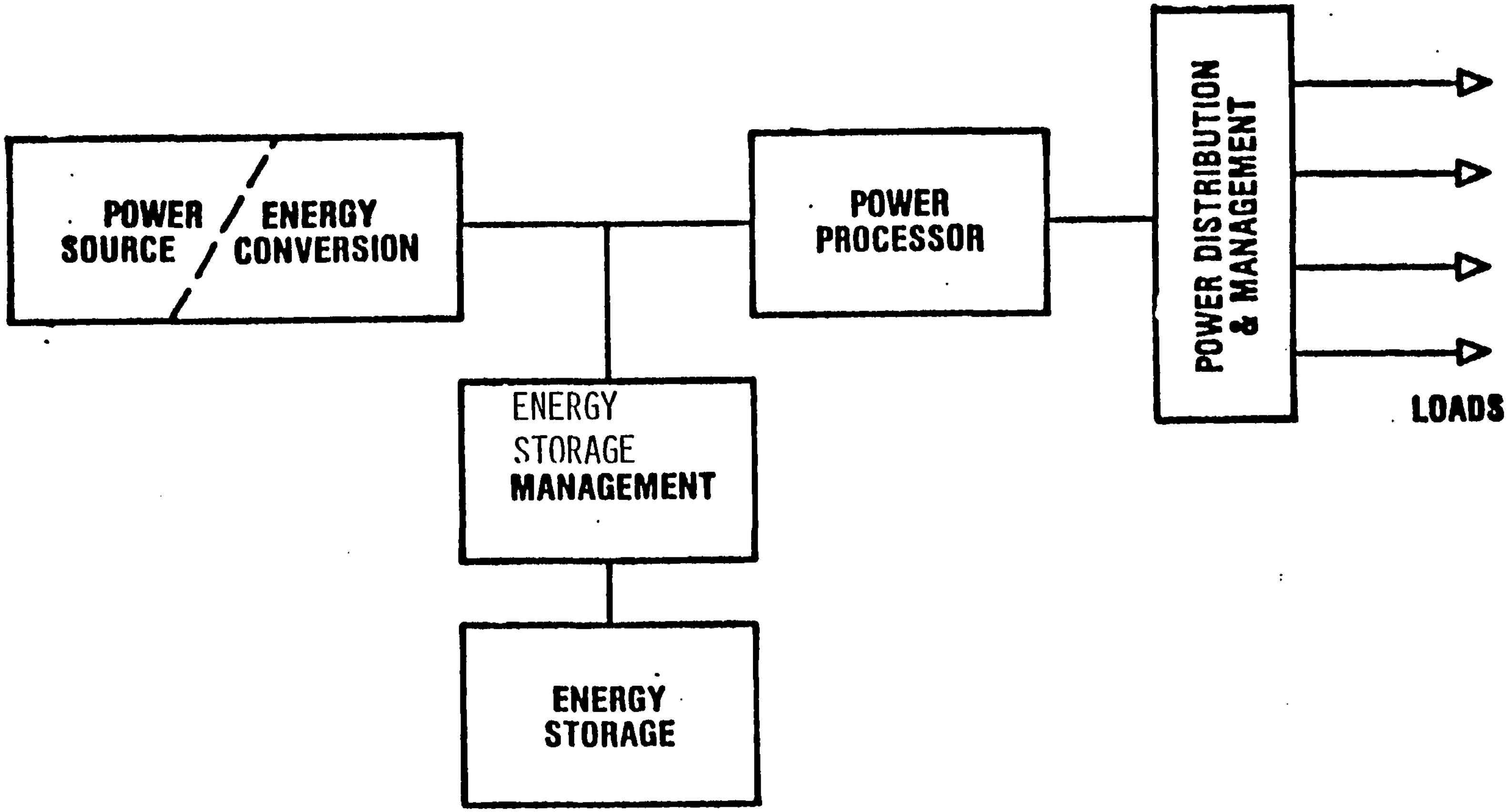
PROPULSION SUBSYSTEM OTV TRADE TREE



PROPULSION SUBSYSTEM RCS TRADE TREE



EPS SIMPLIFIED BLOCK DIAGRAM



EPS POWER SOURCE/ENERGY CONVERSION ALTERNATES EVALUATION

- SOLAR THERMAL-DYNAMIC
  - \- LOW SYSTEM COMPATIBILITY, RELIABILITY
  - \- MEDIUM EFFICIENCY
  - \+ GOOD POWER DENSITY
  - \- MEDIUM VOLUMETRIC DENSITY
  - \- MEDIUM LIFE (DYNAMIC)
  - \+ HIGH RADIATION RESISTANCE
  - \- MEDIUM LIFE CYCLE COST (LCC)
  - \- LIMITED MODULARITY
  - \- MEDIUM DEVELOPMENT RISK
  - \- COMPLEX MANUFACTURING INTEGRATION AND TEST
- SOLAR THERMAL-SOLID STATE (TE)
  - \- LOW SYSTEM COMPATIBILITY, RELIABILITY
  - \- LOW EFFICIENCY
  - \- LOW POWER DENSITY
  - \+ MEDIUM VOLUMETRIC DENSITY
  - \+ LONG LIFE
  - \+ HIGH RADIATION RESISTANCE
  - \- MEDIUM LCC
  - \- LIMITED MODULARITY
  - \+ LOW DEVELOPMENT RISK
  - \- COMPLEX MANUFACTURING, INTEGRATION AND TEST
- SOLAR PHOTOVOLTAIC-PLANAR-GaAs
  - \+ HIGH SYSTEM COMPATIBILITY RELIABILITY
  - \+ GOOD EFFICIENCY
  - \+ GOOD POWER DENSITY
  - \+ GOOD VOLUMETRIC DENSITY
  - \+ LONG LIFE
  - \+ HIGH RADIATION RESISTANCE
  - \+ LOW LCC
  - \+ GOOD MODULARITY
  - \+ LOW DEVELOPMENT RISK
  - \+ GOOD MANUFACTURING INTEGRATION AND TEST
- SOLAR PHOTOVOLTAIC-CONCENTRATOR-GaAs
  - \+ HIGH SYSTEM COMPATILITY
  - \+ HIGH EFFICIENCY
  - \+ GOOD POWER DENSITY
  - \- MEDIUM VOLUMETRIC DENSITY
  - \+ LONG LIFE
  - \+ HIGH RADIATION RESISTANCE
  - \- HIGH INITIAL COST, MEDIUM LCC
  - \+ GOOD MODULARITY
  - \- MEDIUM DEVELOPMENT RISK
  - \- COMPLEX MANUFACTURING, INTEGRATION AND TEST

EPS POWER SOURCE/ENERGY CONVERSION ALTERNATES EVALUATION (CONTINUED)

- NUCLEAR

  NO SYSTEM OR REQUIREMENT COMPATIBILITY

- CHEMICAL

  FUEL CELLS - REGENERATIVE (RFC)

  SEE ENERGY STORAGE SECTION

  (SUITABLE AS BACK-UP SYSTEM)

- CHEMICAL - OTHERS

  NO SYSTEM OR RELATIVE REQUIREMENT COMPATIBILITY

EPS ENERGY STORAGE
ALTERNATIVES EVALUATION

- NiH_2 BATTERIES
  + LOW RISK DEVELOPMENT
  + HIGH CYCLE RATE, LONG LIFE, HIGH RELIABILITY
  + HIGH ENERGY DESNITY
  + HIGH VOLUMETRIC DENSITY
  + HIGH EFFICIENCY
  + VERY GOOD COMPATIBILITY WITH THERMAL & STRUCTURE
  + GOOD MODULAR STRUCTURE
  + FACILITY OF CONNECTION, TESTING, INTEGRATION

- AgH_2 BATTERIES
  + MEDIUM RISK DEVELOPMENT
  − LOW CYCLE RATE, MEDIUM LIFE, HIGH RELIABILITY
  + HIGH ENERGY DENSITY
  + HIGH VOLUMETRIC DENSITY
  + HIGH EFFICIENCY
  + VERY GOOD COMPATIBILITY WITH THERMAL & STRUCTURE
  + GOOD MODULAR STRUCTURE
  + FACILITY OF CONNECTION, TESTING & INTEGRATION

- AgZn BATTERIES
  + AVAILABLE
  − VERY LOW CYCLE RATE, SHORT LIFE
  − LOW RELIABILITY
  + HIGH ENERGY DENSITY
  + HIGH VOLUMETRIC DENSITY
  + HIGH EFFICIENCY
  + VERY GOOD COMPATIBILITY WITH THERMAL AND STRUCTURE
  + GOOD MODULAR STRUCTURE
  + FACILITY OF CONNECTION, TESTING, INTEGRATION.

- $LiTiS_2$ BATTERIES
  − HIGH RISK DEVELOPMENT
  + HIGH CYCLE RATE, LONG LIFE
  + HIGH ENERGY DENSITY
  + HIGH VOLUMETRIC DENSITY
  + HIGH EFFICIENCY
  + VERY GOOD COMPATIBILITY WITH THERMAL AND STRUCTURE
  + GOOD MODULAR STRUCTURE
  + FACILITY OF CONNECTION, TESTING, INTEGRATION

EPS ENERGY STORAGE ALTERNATIVES EVALUATION (CONTINUED)

- FLYWHEELS
  - \- HIGH RISK DEVELOPMENT
  - \- INTERACTION WITH ATTITUDE CONTROL
  - \+ HIGH CYCLE RATE
  - \- MEDIUM ENERGY DENSITY
  - \- MEDIUM VOLUMETRIC DENSITY
  - \- MEDIUM EFFICIENCY
  - \- LOW COMPATIBILITY WITH THERMAL AND STRUCTURE
  - \- COMPLEX BEARING AND STRUCTURE
  - \- COMPLEX CIRCUITRY, TESTING, INTERACTION

- FUEL CELLS
  - \- MEDIUM RISK DEVELOPMENT FOR DYNAMIC SYSTEM
  - \- HIGH RISK DEVELOPMENT FOR SOLID STATE SYSTEM
  - \+ HIGH CYCLE RATE
  - \+ HIGH ENERGY DENSITY
  - \+ HIGH VOLUMETRIC DENSITY
  - \- MEDIUM EFFICIENCY
  - \+ GOOD COMPATIBILITY WITH THERMAL AND STRUCTURE
  - \+ GOOD MODULAR STRUCTURE
  - \+ FACILITY OF CONNECTION, TESTING AND INTEGRATION.

- INDUCTORS/CAPACITORS
  - \- NOT APPLICABLE FOR THIS EPS: VERY LOW DENSITY.
  - \+ SUITABLE FOR POWER PROCESSING, PULSE FORMING AND SPECIAL ENERGY STORAGE REQUIREMENTS.

- THERMAL
  - \- MEDIUM DEVELOPMENT
  - \- MEDIUM RELIABILITY
  - \+ HIGH ENERGY DENSITY
  - \+ HIGH VOLUMETRIC DENSITY
  - \- MEDIUM EFFICIENCY
  - \- LOW COMPATIBILITY WITH THERMAL AND STRUCTURE
  - \- COMPLEXITY OF CONNECTIONS

EPS ENERGY STORAGE MANAGEMENT
ALTERNATIVES EVALUATION

FOR BATTERIES

- SWITCHING, SERIES, BATTERY ADAPTIVE, PEAK POWER TRACKER
  - \+ HIGH COMPATIBILITY WITH INTERFACES
  - \+ OPTIMIZATION OF ENERGY STORAGE PERFORMANCE, HIGH EFFICIENCY, ADAPTIVE
  - \+ HIGH POWER AND VOLUMETRIC DENSITY
  - \+ LOW LCC
  - \+ EASE OF MANUFACTURING, INTEGRATION & TEST
  - \+ MODULAR, ALLOWS REDUNDANCY OPTIONS

- SWITCHING, SHUNT, BATTERY ADAPTIVE

  BACK-UP CHOICE, LESS DESIRABLE THAN SERIES MODE DUE TO SHUNT THERMAL DISSIPATION, LOWER POWER AND VOLUMETRIC DENSITY, AND HIGHER COMPLEXITY (ROOM & LOCATION FOR SHUNTS).

- FOR FLYWHEELS: FLYWHEELS WILL NOT BE SELECTED AS A PREFERRED CHOICE. FLYWHEEL EVALUATION IS PRESENTED IN THE ENERGY STORAGE SECTION.

  NOTE: IN A POSSIBLE ADJUNCT SCENARIO, WHERE A FLYWHEEL MIGHT BE SELECTED, THE DRIVE/ESM CHOIC WILL BE:

  - A CYCLO-CONVERTER FOR AN A.C. DISTRIBUTION, VOLT-SECOND/FREQUENCY = CONSTANT TYPE.
  - A DC/AC INVERTER, VOLT-SECOND/FREQUENCY = CONSTANT TYPE FOR A D.C. DISTRIBUTION.

- FOR FUEL CELLS: REGENERATIVE FUEL CELL SYSTEM (RFCS) IS A BACK-UP CHOICE TO BATTERIES. IF AN RFCS IS SELECTED, THE PREFERRED ESM WILL BE SIMILAR TO THE CHOICE FOR BATTERIES. SEE ALSO ENERGY STORAGE SECTION.
- FOR INDUCTORS/CAPACITORS - N/A, SEE EVALUATION IN ENERGY STORAGE SECTION.
- FOR THERMAL: THERMAL EVALUATION IS PRESENTED IN THE ENERGY STORAGE SECTION. THE THERMAL CONCEPT WILL NOT BE SELECTED AS A PREFERRED OPTION.

EPS POWER PROCESSOR
ALTERNATIVES EVALUATION

- THE EVALUATION OF THE PREFERRED POWER PROCESSOR DEPENDS VERY MUCH ON THE CRITERIA GOVERNING THE POWER MANAGEMENT AND DISTRIBUTION. THE TRADE-OFFS PERFORMED FOR DISTRIBUTION FAVOR THE A.C. SYSTEM FOR THE FOLLOWING:
  - DEGREE OF FLEXIBILITY - LOAD MATCHING (TRANSFORMATION)
  - ISOLATION SIMPLICITY (TRANSFORMATION)
  - SAFETY (HIGH VOLTAGE ISOLATION & MATCHING)
  - SWITCHING & FAULT PROTECTION CAPABILITY (ZERO CROSSING)
  - EASE OF EMI MANAGEMENT (SINUSOIDAL, LOW HARMONIC DISTORTION)
  - SIMPLICITY OF HARDWARE MATCHING (GROWTH POTENTIAL)
  - RELIABILITY (MINIMUM ACTIVE COMPONENTS)
  - POWER TO WEIGHT UTILIZATION RATIO (CENTRAL PROCESSING)
  - EFFICIENCY (MINIMUM NUMBER OF ACTIVE COMPONENTS)
  - COST (ECONOMICS OF SCALE INCLUDED)

- STATEMENTS RELEVANT TO EVALUATION OF CONVERTERS INVERTERS AND COMPONENTS MUST BE UNDERSTOOD TO BE IN THE CONTEXT OF THE PREFERRED A.C. DISTRIBUTION.

EPS POWER PROCESSOR
ALTERNATIVES EVALUATION (CONTINUED)

- DC TO DC CHOPPERS
  - NOT COMPATIBLE WITH A.C. SYSTEM CHOICE
  - SPECIALIZED APPLICATIONS
  - NOT STANDARDIZED BY AVIONICS SYSTEM. LONG HISTORY OF RATIONALIZED AND PRACTICAL REJECTION.
- COMPONENTS
  - AVAILABLE, LIMITED UPGRADING FOR SWITCHING CAPABILITY, EFFICIENCY, INTEGRATION INTO POWER I.C.s

EPS POWER PROCESSOR
ALTERNATIVES EVALUATION

- D.C. TO A.C. INVERTERS

HARMONIC CANCELLATION	RESONANT	SQUARE WAVE
+ GOOD SYSTEM COMPATIBILITY	- NO COMPATIBILITY WITH SYSTEM	- NO COMPATIBILITY WITH SYSTEM
+ HIGH EFFICIENCY	+ HIGH EFFICIENCY	+ HIGH EFFICIENCY
+ HIGH RELIABILITY	+ HIGH RELIABILITY	+ HIGH RELIABILITY
- MEDIUM POWER & VOLUMETRIC DENSITY	+ HIGH POWER & VOLUMETRIC DENSITY	+ HIGH POWER & VOLUMETRIC DENSITY
+ GOOD COMPATIBILITY WITH THERMAL AND STRUCTURE	- MEDIUM COMPATIBILITY WITH THERMAL AND STRUCTURE	+ GOOD COMPATIBILITY WITH THERMAL AND STRUCTURE
+ SUITABLE FOR MODULAR GROWTH	- LIMITED MODULAR GROWTH-RESONANT WITH LOAD	+ SUITABLE FOR GROWTH
+ FACILITY OF MANUFACTURING INTEGRATION AND TEST	- DIFFICULT TO INTEGRATE, RESONANT WITH LOAD	- LIMITED INTEGRATION SUITABILITY, LOW FIDELITY OF WAVEFORM, RESONANCE, EMI
+ LOW RISK DEVELOPMENT (COMPONENT & CONCEPT UPGRADING RECOMMENDED)	- AVAILABLE FOR SPECIAL PURPOSE APPLICATIONS	- AVAILABLE FOR SPECIAL PURPOSE APPLICATIONS
+ LOW LCC	+ LOW LCC	+ LOW LCC
+ SUITABLE FOR VOLTAGE RANGE	+ SUITABLE FOR VOLTAGE RANGE	+ SUITABLE FOR VOLTAGE RANGE
+ SUITABLE FOR STANDARDIZATION	- NON SUITABLE FOR STANDARDIZATION	- NON SUITABLE FOR STANDARDIZATION

EPS POWER DISTRIBUTION MANAGEMENT
ALTERNATIVES EVALUATION

- **A. C.**

  \+ VERY COMPATIBLE WITH S/C SYSTEM POWER LEVEL AND UTILIZATION. A.C. IS SUPERIOR IN THE FOLLOWING AREAS:

  - HIGH DEGREE OF FLEXIBILITY - LOAD MATCHING (TRANSFORMATION)
  - ISOLATION SIMPLICITY (TRANSFORMATION)
  - GOOD SAFETY (HIGH VOLTAGE) (ISOLATION AND MATCHING)
  - EASE OF SWITCHING AND FAULT PROTECTION CAPABILITY (ZERO CROSSING)
  - EASE OF EMI MANAGEMENT (SINUSOIDAL, LOW HARMONIC DISTORTION)
  - SIMPLICITY OF HARDWARE MATCHING (GROWTH POTENTIAL)
  - HIGH RELIABILITY (MINIMUM ACTIVE COMPONENTS)
  - HIGH POWER TO WEIGHT UTILIZATION RATIO (CENTRAL PROCESSING)
  - HIGH EFFICIENCY (MINIMUM NUMBER OF ACTIVE COMPONENTS)
  - LOW LIFE CYCLE COST (LCC) (ECONOMICS OF SCALE INCLUDED)
  - EASE OF MANUFACTURING, INTEGRATION AND TEST

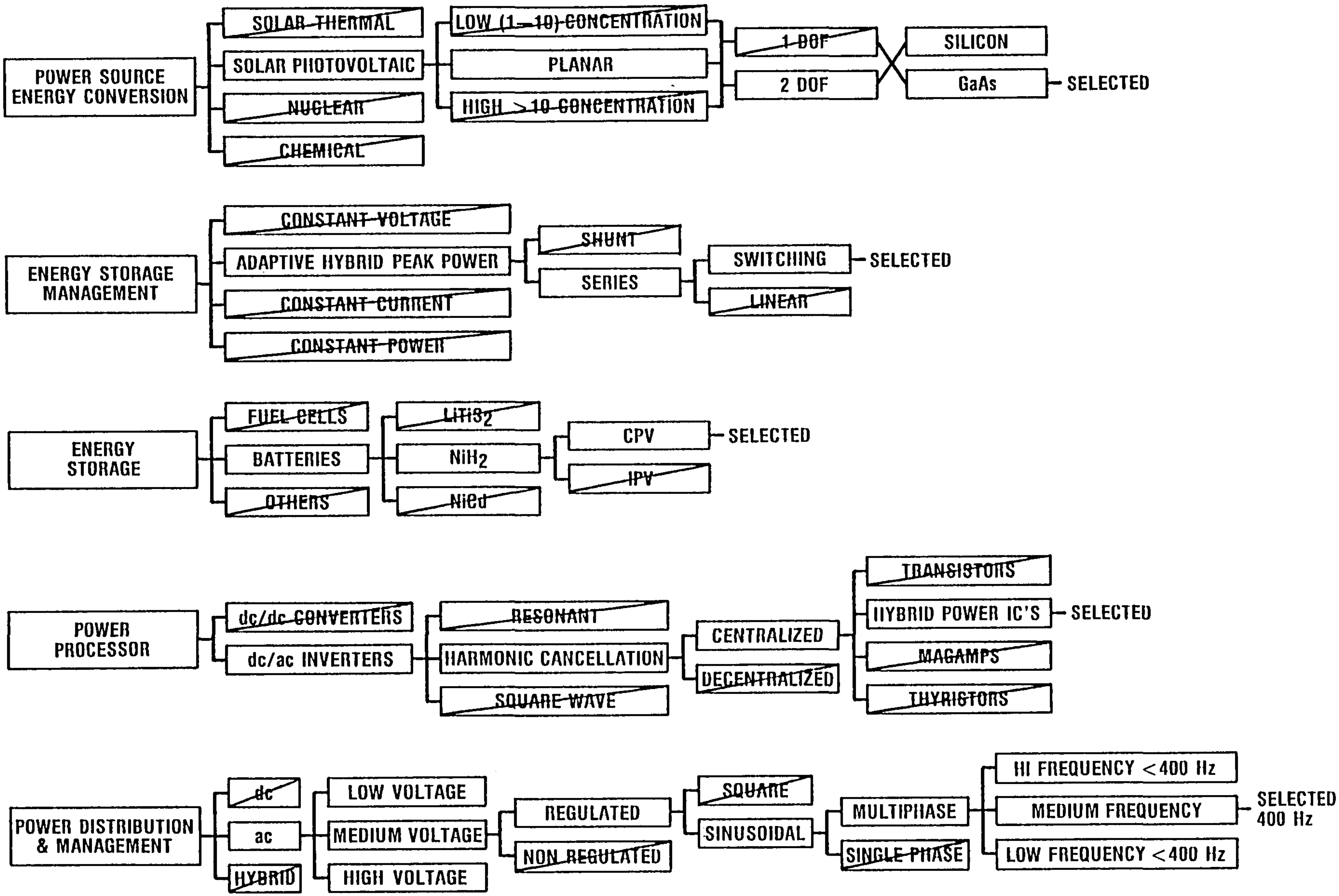
- **D. C.**

  \- LIMITED COMPATIBILITY WITH S/C SYSTEM POWER LEVEL AND UTILIZATION. D.C. SYSTEMS POSE THE FOLLOWING DISADVANTAGES:

  - NO INHERENT FLEXIBILITY
  - NO ISOLATION
  - SAFETY LIMITED TO BRUTE FORCE IMPLEMENTATION
  - DIFFICULT FAULT PROTECTION
  - DIFFICULT EMI MANAGEMENT
  - COMPLEX HARDWARE - USER INTERFACE MUST BE DONE THRU MULTIPLE CONVERSION HARDWARE
  - LOW RELIABILITY
  - LOW POWER AND VOLUMETRIC DENSITY
  - MEDIUM EFFICIENCY - MULTIPLE ACTIVE CONVERTERS
  - HIGH LCC
  - COMPLEX MANUFACTURING INTEGRATION AND TEST

- HYBRID - HYBRID SYSTEMS, WHERE D.C. IS REQUIRED, SHOULD BE CONVERTED FROM THE A.C. SYSTEM.

ADVANCED S/C TECHNOLOGY STUDY
EPS TRADE TREES SUMMARY



Satellite Systems Division

Rockwell International

GN&C ASSEMBLIES

INERTIAL REFERENCE SYSTEM

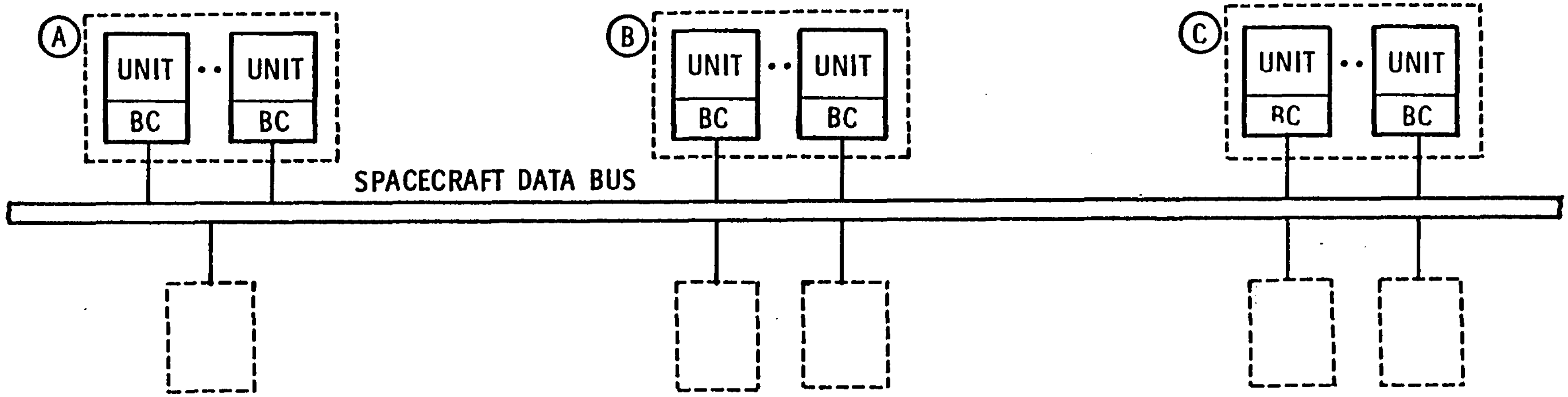
- STAR SENSORS AND GYROS
- EARTH DISK AND SUN
- GYRO COMPASSING
- EARTH MAGNETIC FIELD AND SUN

NAVIGATION MEASUREMENTS

- GROUND TRACKING
- GLOBAL POSITIONING SYSTEM
- EARTH LIMB STAR CROSSING
- STAR AND MOON POSITIONS

ATTITUDE CONTROL
(3-AXIS STABILIZED)

- MOMENTUM WHEELS OR CMG'S
- MAGNETS
- TRIM TABS OR GRAVITY GRADIENT BIAS



TT&C

- UPLINK GND CMDS AND DATA
- DOWNLINK HEALTH AND STATUS DATA
- REMOTE CONTROL FOR LAUNCH AND DOCKING

GN&C DATA PROCESSING

- ATTITUDE AND NAV FILTERS
- ATTITUDE CONTROL LAWS
- PROPULSION, SOLAR ARRAY, AND ANTENNA STEERING
- MODE CHANGES AND COMPONENT SWITCHING
- INITIALIZATION, ACQUISITION, AND RE-ACQ
- HEALTH AND STATUS PROCESSING

CMD/DATA INTERFACES

- DELTA-V PROPULSION
  - ON-OFF AND SELECTION
  - STAGE SEPARATION
- SOLAR ARRAY AND ANTENNA DRIVES
  - MOTOR/ELECTRONICS CMDS
  - POSITION MEASUREMENTS
- PAYLOAD DATA
  - MEASUREMENT DATA
  - MODE COMMANDS

NOTES

- BC - BUS CONNECTOR ELECTRONICS
- UNITS CONTAIN ACCEPTANCE TEST POINTS

SUBSYSTEM: GN&C
ASSEMBLY: NAVIGATION SYSTEM

EVALUATION CRITERIA	GROUND TRACKING	SATELLITE TRACKING	AUTONOMOUS
DEVELOPMENT RISK	+LOW	+MEDIUM	+MEDIUM TO -HIGH
RELIABILITY	+HIGH	+HIGH	+MEDIUM TO -LOW
COMPLEXITY	-HIGH	-HIGH	-HIGH
LIFE	+HIGH	+HIGH	+HIGH TO +MEDIUM
COST	-HIGH	-HIGH	-HIGH
FLIGHT PROVEN	+YES	-NO	-NO
ACCURACY	+HIGH	+HIGH	+HIGH
ACQUISITION COMPLEXITY	-HIGH	-HIGH	-HIGH
SOFTWARE COMPLEXITY	-HIGH	-HIGH	-HIGH
CONTINUOUS OPERATION	-NO	+YES	-NO TO +YES
INTEGRATION WITH OTHER SUBSYSTEMS	+YES	+YES	-NO
INTEGRATION WITH OTHER ASSEMBLIES	-NO	-NO	+YES
WEIGHT	+LOW	+LOW	+LOW
MOUNTING CRITICALITY	+LOW	+LOW	-HIGH TO +MEDIUM
AUTONOMY	-NO	-NO	+YES
HARDENABLE	-NO	-NO	+YES

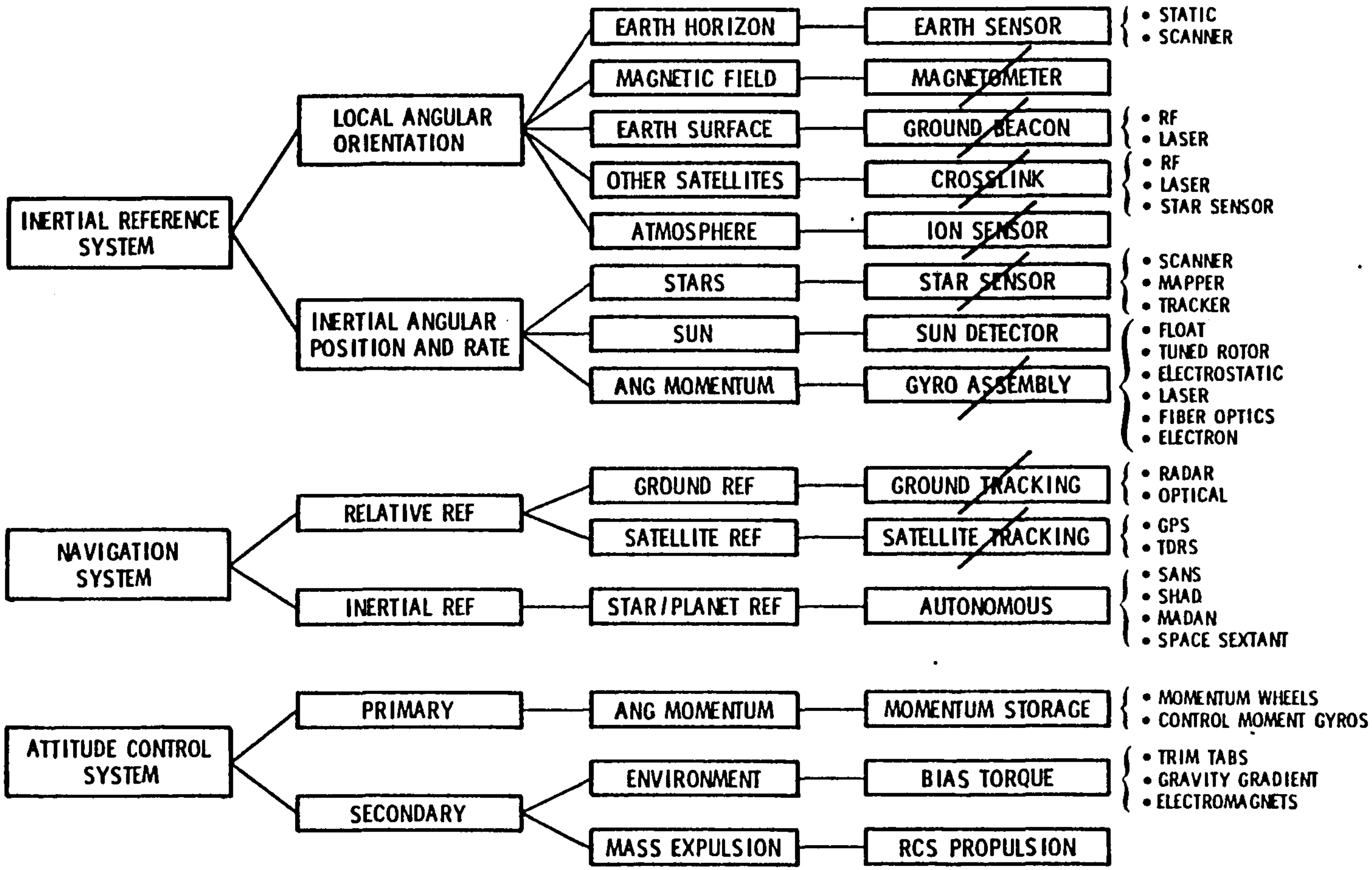
SUBSYSTEM: GN&C
ASSEMBLY: ATTITUDE CONTROL

EVALUATION CRITERIA	MOMENTUM WHEELS	CMG'S	TRIM TABS	GRAVITY GRADIENT	MAGNETS	RCS
DEVELOPMENT RISK	+LOW	+LOW	+MEDIUM	+MEDIUM	+LOW	+MEDIUM
RELIABILITY	+HIGH	+HIGH	+HIGH	+HIGH	+HIGH	+MEDIUM
COMPLEXITY	+MEDIUM	+MEDIUM	+LOW	+LOW	+LOW	-HIGH
LIFE	+HIGH	+HIGH	+HIGH	+HIGH	+HIGH	+MEDIUM
COST	+MEDIUM	+MEDIUM	+LOW	+LOW	+LOW	+HIGH
FLIGHT PROVEN	+YES	+YES	-NO	-NO	+YES	+YES
ACCURACY	+HIGH	+HIGH	-LOW	-LOW	-LOW	+MEDIUM
ACQUISITION COMPLEXITY	N/A	N/A	N/A	N/A	N/A	N/A
SOFTWARE COMPLEXITY	+MEDIUM	+MEDIUM	+LOW	+LOW	+LOW	+MEDIUM
CONTINUOUS OPERATION	+YES	+YES	+YES	+YES	-NO	-NO
INTEGRATION WITH OTHER SUBSYSTEMS	+YES	+YES	-NO	+YES	-NO	+YES
INTEGARTION WITH OTHER ASSEMBLIES	+YES	+YES	+YES	+YES	+YES	+YES
WEIGHT	-HIGH	-HIGH	+LOW	-HIGH	+LOW	-HIGH
MOUNTING CRITICALITY	+LOW	+LOW	-HIGH	-HIGH	+LOW	-HIGH
AUTONOMY	+YES	+YES	+YES	+YES	+YES	+YES
HARDENABLE	+YES	+YES	+YES	+YES	+YES	+YES

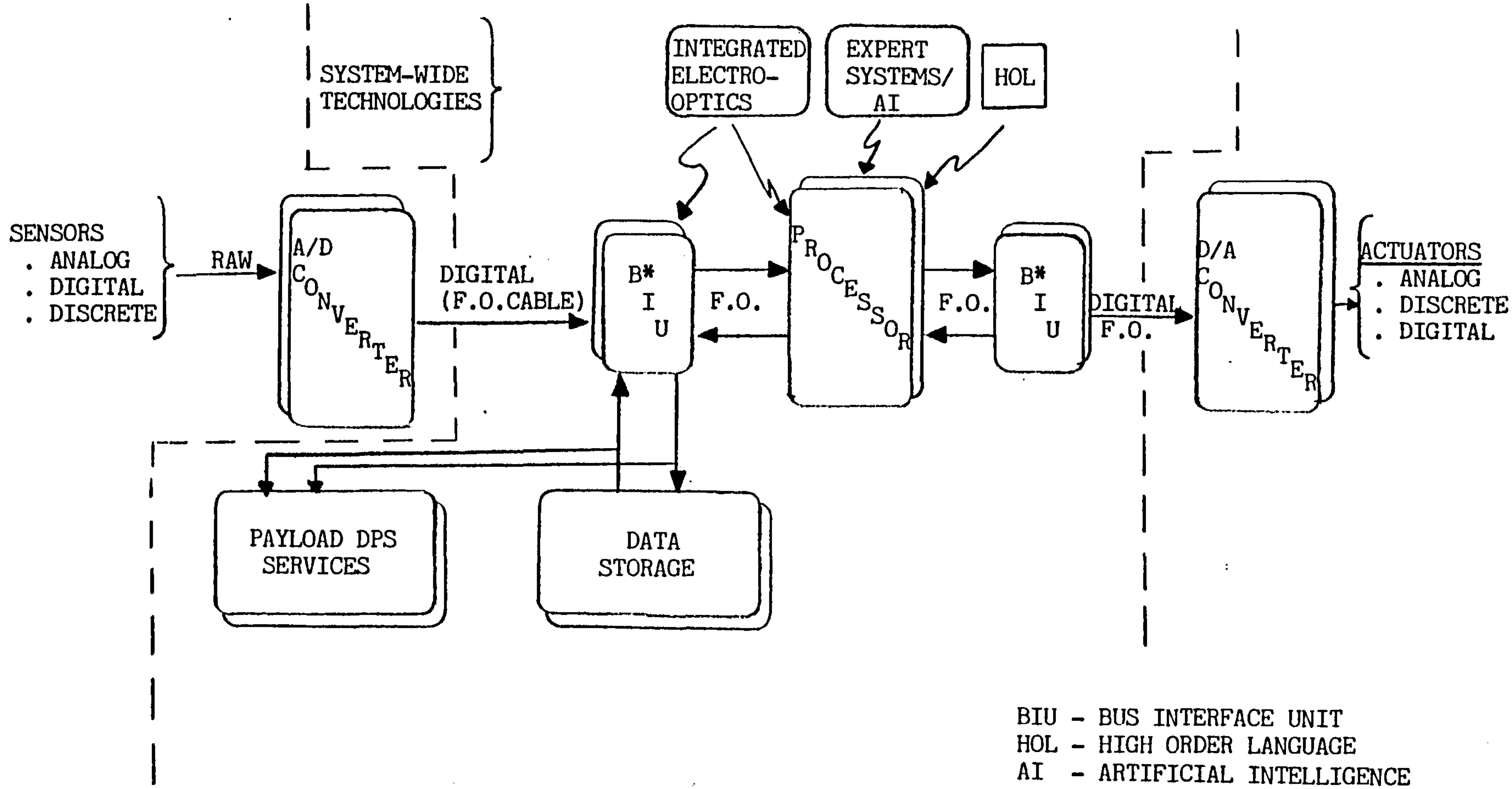
GN&C - INERTIAL REFERENCE ASSEMBLY ALTERNATIVES

	(LOCAL ANGULAR ORIENTATION)					(INERTIAL ANGULAR POS. & RATE)		
EVALUATION CRITERIA	EARTH SENSOR	MAGNET-OMETER	GROUND BEACON	CROSS-LINK	ION SENSOR	STAR SENSOR	SUN DETECTOR	GYRO ASSEMBLY
DEVELOPMENT RISK	+LOW	+LOW	-HI	-HI	-HI	+MED TO -HI	+LOW	+LOW TO -HI
RELIABILITY	+HI	+HI	+HI	+MED	+MED	+MED TO -LOW	+HI	+HI TO -LOW
COMPLEXITY	+LOW	+LOW	+MED	-HI	-HI	-HI	+LOW	-HI
LIFE	+HI	+HI	+HI	+MED	?	+HI TO -LOW	+HI	+HI TO -LOW
COST	+MED	+LOW	+MED	-HI	-HI	-HI	+LOW	-HI
FLIGHT PROVEN	+YES	+YES	-NO	-NO	-NO	+YES TO -NO	+YES	+YES TO -NO
ACCURACY	+MED	+LOW	+LOW	+HI	?	+HI	-LOW TO +MED	+HI
ACQUISITION COMPLEXITY	+MED	+LOW	+LOW	-HI	-HI	-HI	+LOW	-HI
SOFTWARE COMPLEXITY	+MED	-HI	+LOW	-HI	-HI	-HI	+LOW	-HI
CONTINUOUS OPERATION	+YES	-NO	-NO	+YES	-NO	+YES TO -NO	-NO	+YES
INTEG'N W/OTHER SUBSYSTEMS	-NO	-NO	+YES	+YES	-NO	-NO	+YES	-NO
INTEG'N W/OTHER ASSEMBLIES	+YES	+YES	+YES	+YES	+YES	+YES	+YES	+YES
WEIGHT	+MED	+MED	+LOW	+MED	+LOW	+LOW TO +MED	+LOW	+MED TO +LOW
MOUNTING CRITICALITY	-HI	-HI	+LOW	-HI	-HI	-HI	-HI	+LOW
AUTONOMY	+YES	+YES	-NO	-NO	+YES	+YES	+YES	+YES
HARDENABLE	-NO	+YES	+YES	+YES	?	+YES	+YES	+YES

GN&C TRADE TREE



DATA PROCESSING SYSTEM COMPONENT DIAGRAM



BIU - BUS INTERFACE UNIT
HOL - HIGH ORDER LANGUAGE
AI - ARTIFICIAL INTELLIGENCE

TYPICAL SATELLITE PROCESSING REQUIREMENTS

HOUSEKEEPING FUNCTIONS

- SPACECRAFT ENVIRONMENTAL CONTROL
- VEHICLE STATUS
- POWER MANAGEMENT
- DIAGNOSTICS: FAULT DETECTION & CORRECTION
- EXECUTIVE

STATION KEEPING FUNCTIONS

- TELEMETRY, COMMAND & CONTROL
- ATTITUDE CONTROL
- NAVIGATION
- EPHEMERIS
- ANTENNA POINTING
- STAR/EARTH SENSING

MISSION DATA PROCESSING

- DATA ACQUISITION
- FILTERING
- MASSAGING/ENHANCING
- COMPRESSING (REDUCING BANDWIDTH)
- MISSION SPECIFIC ALGORITHM EXECUTION
- MESSAGE GENERATION

DATA MANAGEMENT DEFINITION

INPUT
- SENSORS
- RECEIVERS
- TERMINALS
- DEDICATED PROCESSORS

INTERCONNECT ⇒ NETWORK

PROCESS
- PROCESSORS
- PROCESSING
  - OPERATING SYSTEM
  - DIST. PROC. CNTL
  - RM OF PROC. & NETWORK
- INTERCONNECT CONTROL
- DATA BASE MGMT
- DATA STORAGE
- COMMUNICATION CNTL
- DATA & PROCESSING SECURITY

INTERCONNECT ⇒ NETWORK

OUTPUT
- EFFECTORS
- TERMINALS
- SENDERS
- DEDICATED μPs

OTHER SUBSYSTEMS CONSIST OF:
- SUBSYSTEM HARDWARE
- SENSORS
- EFFECTORS
- APPLICATION SOFTWARE DEFINITION
- EMBEDDED μP (WHERE APPLICABLE) & μP SOFTWARE

DMS ASSEMBLIES EVALUATION (1)

PROCESSORS

Identification	Delco IUS 362 S	RCA DHSP 234	GE DSCS III ACE (Alpha 16)	Litton 4516 E	CDC 469
Weight (pounds)	52	11	10	13	10
Power (watts)	200	10	25	80	20
Word Length	16/32	16/32	16	16/32	16/32
Memory size	64K (32K x 39 ECC)	64K 16K used)	1K CMOS RAM 8K PPOM	64K	16K
Memory Technology	CMOS	CMOS	1K CMOS 8K PPOM	CMOS	Plated Wire or CMOS
CPU Technology	Bipolar	CMOS	Bipolar	Bipolar	PMOS
Executing Speed (sec)	700 KIPS	100 KIPS	20 KIPS		100 KIPS
Add	1	4.8	5.5	2.5	4
Multiply	2.8	60	x20.5	21	10.4
Floating Point	Yes	No	No	Yes	No
User	IUS	DMSP	DSCS	Space Sextant	Classified
Time Frame	1975	1970	1975	1978	1975

SPACE QUALIFIED HOWEVER TOO LARGE, HEAVY & POWER HUNGRY. ALSO, THRUPUT SPEED LIMITS GROWTH.

0

DMS ASSEMBLIES EVALUATION (2)

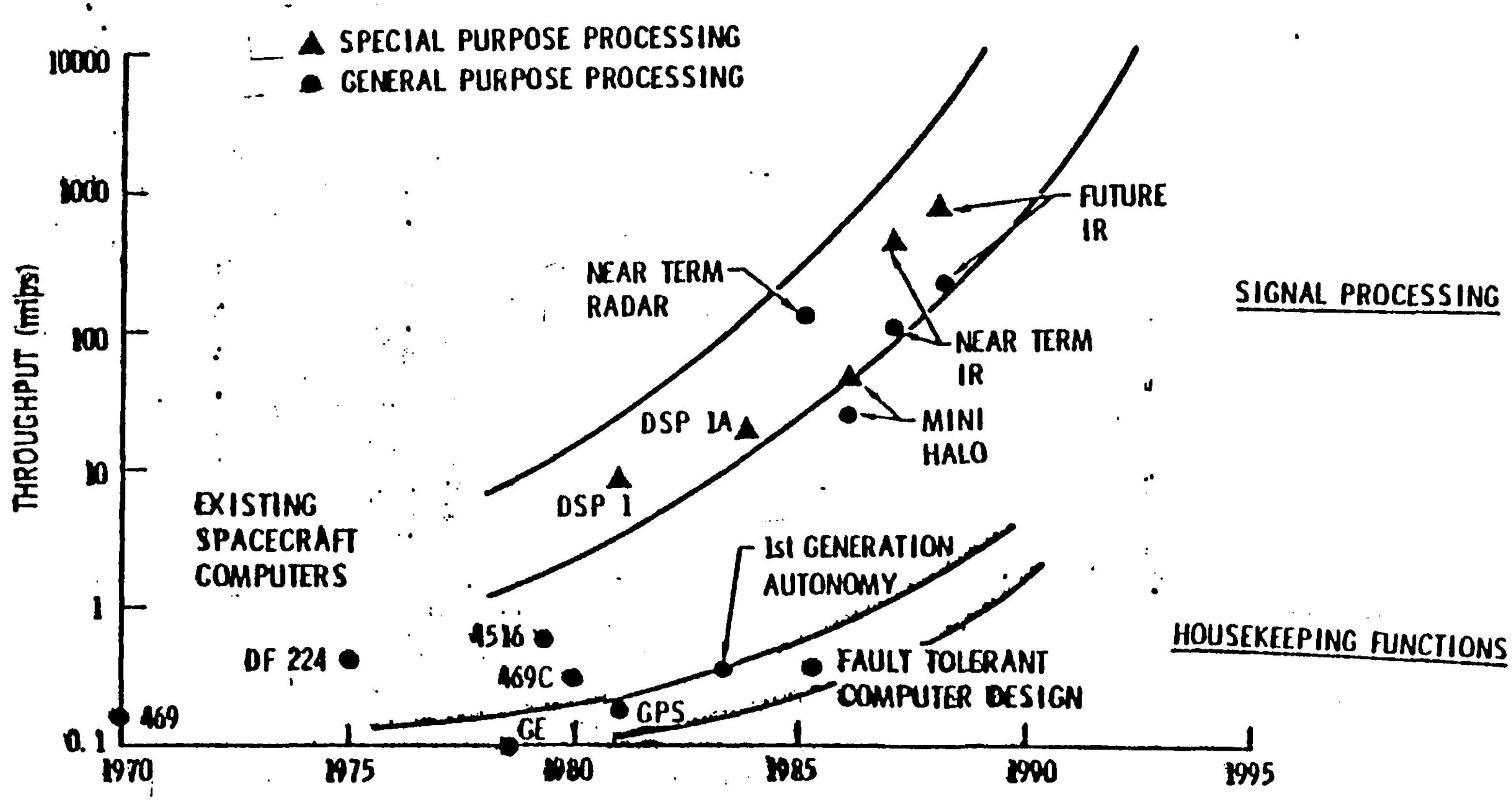
PROCESSORS

Manufacturer	Motorola	Intel	Rockwell	RCA		Zilog	Fairchild	Texas Inst.	AMD
Processor ID.	68000	8086	AAMP	1802	GPU	Z8000	9440/45	9900	2901B
Word Length (Bits)	16	16	16	8	8-bit slice	16	16	16	4-bit slice
Technology	NMOS	NMOS	CMOS/SOS	CMOS	CMOS/SOS	NMOS	I^3L	I^2L	Bipolar
Clock Freq. (MHz)	8	5	>5	6.4		8	10	4	15
Instruction Speed Shortest Longest	 0.5 NA	 0.4 38	 NA NA	 2.5 3.75	 0.75 NA	 0.75 90	 NA NA	 2 31	 0.088 NA
Power (MW)	1200	1375	<400	40	100			>500	900
Qual. Status	None	Spec. (1980)	None	Qual. (1980)	1982?	None	Spec. (1980/81)	Qual. (1980)	1979
Space Flt. Exp.	None	None	None (GPS/UE)	Mag Sat SMM Galileo (1984) ST(1982) Min Veh	None (GPS/UE)	None	None	ST(1982) Teal Ruby	DSCS
Direct Addressing (Words)	16M	1M	64K	64K	NA	48K	64K	NA	
Radiation Hard	No	No	Potentially	Potentially	8	No	Potentially	Potentially	Potentially
Minimum Number of IC Packages for End Product	>5	>5	1	1		>5	>5	>3	>6

CAN SATISFY CURRENT REQUIREMENTS - WILL NOT MEET FUTURE REQUIREMENTS

DMS ASSEMBLIES EVALUATION (3)

PROCESSORS (PROGRAM PROJECTIONS AND PROCESSOR CAPABILITIES)



DMS ASSEMBLIES EVALUATION (4)

MASS MEMORY

MEMORY TYPE	DISK	TAPE	BUBBLE	CORE OPTICAL
CAPACITY (MEGABYTES)	35	3	3	
SIZE (IN)	12 x 14 x 12	9 x 13 x 14	8 x 8 x 18	
VOL (IN^3)	3530	1640	1040	4160
WT. (LBS)	80	30	46	
POWER (WATTS)	217	90	75	
MTBF	5,000 HRS	10,000 HRS	320,000 HRS	
TACC			48 MS	400 NS
COST				

DMS ASSEMBLIES EVALUATION (5)

INTERCONNECTIONS

TYPE	TWISTED SHIELDED PAIR 22 GAGE	COAX 58/U	FIBER 50 MICRON GRADED INDEX
COST/100 FT	$31.50	$24.70	$42.70
WT/100 FT	9.0 LB	4.0 LB	0.45 LB
CONNECTOR			
TYPE	TWIN PIN	BNC	SMA
COST	$5.00	$6.40	$10.00
TYPICAL DATA RATES	15 MBPS	50 MBPS	400 MBPS
COST/MBIT	$3.42	$0.90	$0.19
WT/MBIT	0.83 LB	0.11 LB	0.0015 LB
POWER/MBIT	0.746 MW	0.400 MW	0.162 MW

FIBER OPTICS

TYPE	RADIATION	TEMPERATURE	VACUUM
ALL PLASTIC	GOOD FOR LOW DOSE	POOR < $-40^{o}C$	COULD BE LONG-TERM PROBLEM
POLYMER CLAD SILICA HIGH OH CONTENT	VERY GOOD	SOME ATTENUATION AT LOW TEMPS	COULD BE LONG-TERM PROBLEM
ALL GLASS			
PURE FUSED SILICA CORE	VERY GOOD	GOOD	GOOD
GE DOPED SILICA CORE	VERY GOOD	GOOD	GOOD
GE-P DOPED SILICA CORE	GOOD	VERY GOOD	GOOD
GE-B DOPED SILICA CORE	VERY GOOD	GOOD	GOOD

DMS ASSEMBLIES EVALUATION (6)

SUBSYSTEM INTERFACE

BUS INTERFACE UNIT (EMBEDDED VHSIC μP)

+ CONVERSION TO EQUIPMENT SPECIFIC COMMANDS & COMMAND SEQUENCES AT EQUIPMENT INTERFACE
+ MANAGES BUS, SITE AND NETWORK CONNECTIVITY VIA SOFTWARE
+ PERMITS TECHNOLOGY INFUSION AND SYSTEM GROWTH
+ PERMITS ON-CHIP SAMPLING, A/D CONVERSION, SHIFT REGISTER DELAY, DIGITAL FILTERING, DEMULTIPLEXING ERROR DECODING & CORRECTION, AND SYNCHRONIZATION FUNCTIONS
+ PERMITS WIDER RANGE OF ARCHITECTURES
- VERIFICATION MORE COMPLEX AND LESS DETERMINATE

MULTIPLEXER

+ WELL-KNOWN TECHNOLOGY
+ PREDICTABLE ACTIONS/TIMING (TIMEWISE REPETITIVE)
- SENSITIVE TO TEMPERATURE (LEAKAGE CURRENT PRODUCES INPUT OFFSET ERROR)
- POWER GLITCHES MAY CAUSE LATCH-UP (SINGLE CHANNEL HELD ON)
- SIGNAL CONDITIONING, CONVERSION AND INTERFACE HANDLED SEPARATELY AND TOTAL DIGITAL ACQUISITION THEN INTEGRATED UNDER CENTRALIZED CONTROL

A/D CONVERTER

+ ESTABLISHED TECHNOLOGY
- SINGLE STRING, INCREASE WIRING
- POWER REQUIREMENTS (~ WATTS ECL/SILICON; ~ mw CMOS, GaAs)

DMS ASSEMBLIES EVALUATION (7)

ORGANIZATION

DISTRIBUTED CONTROL

+ PROVIDES BEST THRUPUT, FLEXIBILITY, AND GROWTH CAPABILITIES
+ BEST FITS THE MODULARITY, EVOLVING SATELLITE REQUIREMENTS
- HIGHEST RISK CANDIDATE DUE TO IMMATURITY OF REDUNDANT, DISTRIBUTED SYSTEMS

DEDICATED SUBSYSTEM - CENTRAL CONTROL

+ LOW RISK ARCHITECTURE
+ SOFTWARE & HARDWARE DIVIDED INTO FUNCTIONAL LEVELS - SUBSYSTEM/SUPERVISORIAL
- MAY REQUIRE MORE HARDWARE THAN OPTIMAL
- TECHNOLOGY INFUSION MAY BE DIFFICULT

CENTRAL CONTROL

+ MATURE SYSTEM CONCEPT
+ PACKAGING CONCEPT PROBABLY REDUCES TOTAL SIZE/POWER/WEIGHT
- MAY NOT HAVE ADEQUATE I/O OR PROCESSING THRUPUT
- DOES NOT SUPPORT MODULARITY/OR GROWTH REQUIREMENTS

DMS ASSEMBLIES EVALUATION (8)

ARCHITECTURE SUMMARY*

	CENT	DIST/SEG CENT	DIST
PROCESSING REQUIREMENTS	3	2	1
RISK	2	1	3
GROWTH	3	2	1
RESOURCE SHARING	3	2	1
REDUNDANCY MGMT	3	2	1
RELIABILITY	3	2	1
VERIFICATION/MAINTAINABILITY	3	2	1
SIZE/POWER/WEIGHT	1	3	2
BUSSING/CABLES	3	2	1

RANKED IN NUMERICAL ORDER, "1" BEST

*COMPLETELY SUBJECTIVE REVIEW OF THREE ARCHITECTURES; EVALUATION WILL BECOME OBJECTIVE AND QUANTIFIABLE AS REQUIREMENTS BECOME FIRM AND DESIGN DEFINED.

DMS ASSEMBLIES EVALUATION (9)

LANGUAGES

PASCAL

+ MATURE
+ MANY COMPILERS AVAILABLE
+ LARGE LABOR FORCE
+ CAN UPDATE TO ADA
- NOT DOD APPROVED - WAIVER REQUIRED
- REQUIRES EXTENSIONS FOR REAL TIME

ADA

+ DOD STANDARD
o DESIGNED FOR MILITARY APPLICATIONS
+ SUPPORT TOOLS INCLUDED
- IMMATURE
- NEW TECHNOLOGY - RISK AND UNCERTAINTY

JOVIAL

+ CURRENT AF STANDARD
+ DESIGNED FOR EMBEDDED SYSTEMS
+ MATURE LABOR FORCE
+ SUPPORT TOOLS AVAILABLE
- EARLY OBSOLESCENCE
- LESS MATURE COMPILERS THAN PASCAL

ASSEMBLY & MACHINE

+ POTENTIALLY MORE EFFICIENT
- DIFFICULT TO DOCUMENT/MAINTAIN/MANAGE
- DIFFICULT TO VERIFY
- LABOR INTENSIVE TO CODE, DEBUG, INTEGRATE - COSTLY

DMS ASSEMBLIES EVALUATION (10)

HIGH ORDER LANGUAGES	FORTRAN 77	PASCAL	CONCURRENT PASCAL	JOVIAL J73	JOVIAL J73C	ADA
SUPPORTS STRUCTURED PROGRAMMING	SORT OF	YES	YES	YES	YES	YES
DOD APPROVED	NO	NO	NO	YES	YES	YES
AVAILABLE FOR 1750 TARGET	NO	YES	NO	YES	NO	SOON
AVAILABLE FOR VAX HOST	YES	YES	YES	YES	YES	SOON
SUPPORTS REAL-TIME PROGRAMS	NO	NO	YES	YES	YES	YES
SUPPORTS MULTI-TASKING	NO	NO	YES	NO	NO	YES
FIXED POINT DATA TYPES	NO	NO	NO	YES	YES	YES
LANGUAGE IS MATURE & STABLE	YES	YES	YES	NO	NO	NO
COMPILERS ARE MATURE & STABLE	YES	YES	NO	SOME	NO	NO
SUPPORT TOOLS AVAILABLE	MANY	SOME	FEW	YES	NO	EVENTUALLY
AVAILABLE PROGRAMMER BASE	LARGE	LARGE	MODERATE	SMALL	SMALL	SMALL

ADA IS NOT MATURE, BUT HAS STRONG GOVERNMENT BACKING

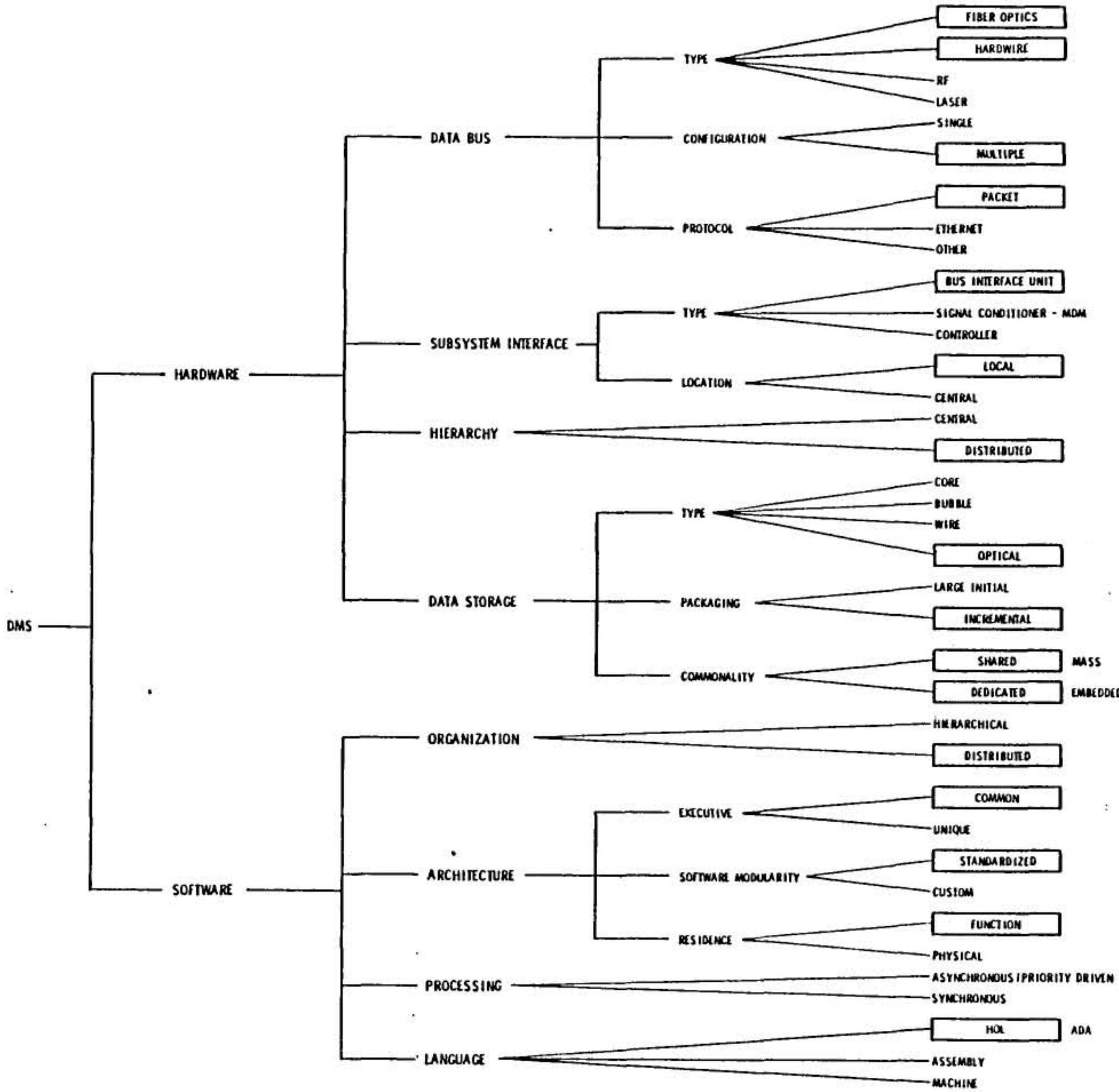
Satellite Systems Division Rockwell International

DMS ASSEMBLIES EVALUATION (11)

PERFORMANCE CRITERIA	PROTOCOLS				
	TDMA	CSMA	1553B	TOKEN	ADAPTIVE
ACCOMMODATES GROWTH OF NODES	NO	YES	NO	YES	YES
(- TRAFFIC)	YES	DEGRADES	YES	YES	YES
(- HIGHER SPEED)	YES	NO	YES	YES	MAY
INTENDED TRAFFIC TYPES - MIXED	NO	NO	NO	YES	NO
(BURSTY)	NO	YES	NO	YES	YES
GUARANTEED DELIVERY - USE OF ACK	(TOPOLOGY & PROTOCOL VARIANT DEPENDENT)				
PRIORITY - STATICALLY ASSIGN NODE PRIORITY	YES	NO	YES	YES	CAN BE
- DYNAMICALLY ASSIGN MODE PRIORITY	NO	NO	NO	NO	YES
- BY MESSAGE	NO	NO	NO	ATTEMPTS	NO
SENSITIVE TO - TOPOLOGY	NO	YES	NO	NO	YES
- MEDIA	SOME	YES	SOME	SOME	YES
MAXIMUM THRUPUT	HIGH	LIMITED	HIGH	HIGH	VERY HIGH
STABILITY & HIGH LOADS	YES	NO	YES	YES	YES
DELAY - LOW LOADS	HIGH	LOW	HIGH	HIGH	VERY LOW
- HIGH LOADS	LOW	HIGH	LOW	LOW	LOW
COMPLEXITY OF PROTOCOL	LOW	MED	MED/LOW	HGIH	VERY HIGH
ROBUSTNESS (WRT NODE FAILURE)	LOW	VERY HIGH	MED	HIGH	HIGH
MATURITY OF PROTOCOL (STANDARDIZATION)	HIGH	HIGH	HIGH	MED	LOW
VLSI IMPLEMENTATION	YES	YES	YES	1984	--
DEMONSTRATED	YES	YES	YES	EXPERIMENTAL	NO

DMS ASSEMBLIES SELECTION

COMPONENT	TYPE	SoA
PROCESSOR	VHSIC	1
STORAGE	OPTICAL	1
CABLES/CONNECTORS	FIBER OPTIC	2
	INTEGRATED OPTO-ELECTRONICS	1
INTERFACE	BUS INTERFACE + VHSIC	2
ORGANIZATION	DISTRIBUTED	2
LANGUAGE	ADA	2
PROCESSING	PLESIO SYNCHRONOUS	2
ARCHITECTURE	STANDARDIZED/FUNCTIONAL	1



DATA MANAGEMENT TRADE TREE